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**INSTALLATION AND HYDROGEOLOGIC  
EVALUATION OF TEST WELLS  
AND DESIGN OF A GROUND-WATER  
RECOVERY SYSTEM  
TYSON'S SITE  
MONTGOMERY COUNTY, PENNSYLVANIA**

**PREPARED FOR  
CIBA-GEIGY CORPORATION  
ARDSLEY, NEW YORK**



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## EXECUTIVE SUMMARY

The Tyson's Site lies about 500 feet to the south of the Schuylkill River in Montgomery County, Pennsylvania. The surficial materials at the site and its vicinity are underlain by a fractured bedrock aquifer which extends beneath the Schuylkill River and beyond. Previous hydrogeologic investigations of the bedrock aquifer indicated that the aquifer was contaminated with compounds disposed at the site. Part of this contaminated ground water discharges into the Schuylkill River and part continues to move northward under the river.

To design a recovery system capable of intercepting the flow of contaminants into the Schuylkill River, six test wells were installed into the bedrock, tested and sampled. The results of these field investigations indicate that the bedrock has an average transmissivity of about 500 ft<sup>2</sup>/d. The permeability of the bedrock decreases with depth and thus most of the transmissivity is attributable to the upper 50 feet of bedrock. In contrast, the higher concentrations of contaminants in ground water occur in the deeper parts of the bedrock.

A numerical simulation model of the bedrock aquifer was developed and used in conjunction with a particle tracking program to evaluate different ground-water extraction scenarios. Based on these model analyses, a recovery system pumping a total of 350 gpm is proposed to intercept contaminated ground water discharging into the Schuylkill River. The proposed system consists of 13 wells, open to 150 feet of bedrock and located along a line parallel to and 50 feet from the south bank of the river. The 6 existing test wells will be incorporated into the system and 7 new wells will be installed. To monitor the performance of the recovery system, the installation of six shallow monitoring wells is also proposed.

The proposed recovery system and associated treatment facility will not be operative until September 1989. As an initial measure that could be implemented quickly and alleviate most, if not all, of the river contamination, a partial recovery system has been proposed. This initial recovery system, consisting of 7 wells and pumping a total of 200 gpm, will intercept the ground water from the most contaminated area in the upper 50 feet of the bedrock. The system will utilize 3 of the existing test wells and 4 new wells open to only the upper 50 feet of the bedrock. The pumped ground water will be treated using a mobile temporary treatment plant.

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REPORT

REPORT

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## 1.0 INTRODUCTION

The Tyson's Site, in Upper Merion Township, Montgomery County, Pennsylvania, (see Figure 1), is a former sandstone quarry which was reported to have been operated between 1962 and 1970 as a disposal site for septic and chemical wastes. The wastes were disposed in a series of unlined lagoons within an approximately four-acre plot. The site lies about 500 feet to the south of the Schuylkill River and is bordered to the east and the west by unnamed tributaries to the river (see Figure 2). The high-wall of the former quarry forms the southern boundary of the site, and a Conrail railroad switching yard lies to the north of the site. The area between the Conrail tracks and the river is covered by floodplain sediments and wetlands. The surficial materials at the site and its vicinity are underlain by fractured bedrock which extends beneath the Schuylkill River into Norristown and beyond with an average dip of 12 degrees to the north-northwest.

The Pennsylvania Department of Environmental Resources ordered the site closed in 1973. During closure, the lagoons were reported to have been emptied, backfilled, vegetated, and the contents transported offsite. Between January 1983 and the present, a series of investigations were conducted at the site by contractors to the U.S. Environmental Protection Agency (EPA) and by Environmental Resources Management, Inc. (ERM), consultants to CIBA-GEIGY Corporation, one of the potentially responsible parties.

The investigations conducted by EPA contractors were primarily aimed at developing and refining an EPA-proposed remedial action for the On-Site Area. Those conducted by ERM on behalf of CIBA-GEIGY addressed issues related to the Off-Site Area, including the deep fractured bedrock aquifer.

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The investigation of the deep aquifer included the installation of one background well upgradient of the site and of eleven well nests in the area between the site and the Schuylkill River. The locations of these well nests are shown in Figure 2. Except for well nests 2, 10 and 12, each well nest consisted of three wells completed in a shallow (S), intermediate (I) and deep (D) interval within the bedrock. Well nest 2 consisted of two wells completed in a shallow and an intermediate interval. Well nest 12 also consisted of two wells completed in shallow and deep intervals. Well nest 10 included a fourth well completed in an extra-deep (XD) interval. Hydrogeologic tests were conducted in these well nests to determine the hydraulic properties of the bedrock aquifer, and the wells were sampled to determine the quality of ground water in the aquifer. \*

The results of these investigations (ERM, 1987) indicated that the bedrock aquifer downgradient of the site was contaminated with compounds disposed of at the Site. These compounds were found both in dissolved form and as dense non-aqueous phase liquids (DNAPLs). However, because of the fractured nature of the bedrock aquifer, the occurrence of DNAPLs was erratic. In wells where the DNAPL was found, the depth of occurrence differed from well to well. Also, attempts to recover DNAPL from wells were not successful (ERM, 1987).

Ground water in the bedrock moves northward, toward the Schuylkill River. Part of this ground water discharges into the river and part continues to move northward under the river. As a possible means of preventing the northward migration of ground water contaminated from sources on-site and/or from DNAPLS within the bedrock under the site and between the site and the river,

S. S. Papadopoulos & Associates, Inc. (SSP&A) proposed the installation of a capture system consisting of a number of extraction wells located downgradient of the site and parallel to the south bank of the river (SSP&A, 1987).

Under the terms of a Partial Consent Decree entered into on February 19, 1988 by the United States, the State of Pennsylvania and the Settling Defendants, which include the CIBA-GEIGY Corporation, the Settling Defendants agreed to install and operate a ground-water recovery and treatment system designed to intercept the flow of contaminants to the Schuylkill River. CIBA-GEIGY assigned the task of developing the design of the ground-water recovery component of the recovery and treatment system to SSP&A.

To obtain the data necessary for the design of an extraction well system\* which would effectively capture contaminated ground water that may presently be discharging into the Schuylkill River, six tests wells were installed along a line about 50 feet from and parallel to the south bank of the river. The wells were drilled to an average depth of 180 feet, penetrating about 150 feet into bedrock. Hydrogeologic tests were conducted in the wells to determine the hydraulic properties of the bedrock at different depth intervals and to estimate well yields and pumping lifts. Also, water samples were obtained and analyzed to estimate the initial concentration of contaminants in the ground water to be extracted.

Data collected during these field investigations were evaluated and the results were used to develop a numerical, three-dimensional simulation model of the bedrock aquifer. This model was used in conjunction with a particle tracking program developed by SSP&A to assess the effectiveness of different extraction well schemes and to develop the design of the ground-water recovery

system. The simulation model was also used to evaluate a partial recovery system proposed by ERM as an initial measure that may be implemented quickly and that may alleviate the contamination in the Schuylkill River by intercepting most of the contaminated ground water in the upper 50 feet of the bedrock aquifer.

This report describes the field investigations and analyses conducted to design the ground-water recovery system, presents the proposed design for the system and the results of the evaluation of the initial recovery system proposed by ERM.

## 2.0 DESCRIPTION OF FIELD INVESTIGATION

Six bedrock test wells were installed, tested, sampled, and monitored at the floodplain of the Schuylkill River north of the Tyson's site between November 1987 and March 1988. Details of the field program are described below.

### 2.1 WELL INSTALLATION

The six test wells, designated as EW-1 through EW-6, were installed into bedrock underlying the floodplain of the Schuylkill River at the locations shown on Figure 2. A schematic diagram of a typical test well is shown on Figure 3, and a drilling log for each well is provided in the Appendix. A summary of the well construction details is contained in Table 1. The wells were constructed with a sufficiently large borehole diameter (8 1/2-inch) so that, if productive, they could be incorporated into the design of the recovery system as extraction wells. The drilling equipment used to install the wells was cleaned with a high pressure steam wash prior to its use at each well location. Steel surface casing was also "steam cleaned" before installation. Water produced during drilling was either pumped to an onsite facility where it was treated and subsequently released into the river or it was trucked away for offsite treatment and disposal. Rock cuttings were captured and transported to an offsite disposal facility. A site safety officer was present during the drilling and testing activities, and monitored the work area for organic vapors.

Solid-stem augers were used to drill through the unconsolidated materials to the bedrock surface at wells EW-1, EW-2, EW-3, EW-4 and EW-5. Well EW-6

was drilled to bedrock with a roller bit. When bedrock was reached, an outer steel surface casing of 12-inch inside diameter (I.D.) was set to the top of the rock to prevent caving of the borehole. The borehole was then advanced a minimum of 5 feet into solid bedrock using a down-the-hole air hammer with a 12-inch diameter carbide button bit. The hole was cleared free of water and rock cuttings by blowing compressed air through the drill rods until the discharged water was clear. Steel surface casing of 8 3/4-inch or 8 7/8-inch I.D. (see Table 1) was then set to the bottom of the borehole and tremie-grouted to the land surface to seal off water in the unconsolidated materials. The cement grout was left to set for a minimum of 12 hours before bedrock drilling resumed.

Further bedrock drilling was accomplished with an 8 1/2-inch diameter carbide button bit attached to the down-the-hole air hammer. Drilling proceeded in three 50-foot depth intervals. After drilling each 50-foot interval of bedrock, the well was developed by using compressed air until the discharged water was clear and free of suspended solids. Following development, drilling was suspended to allow for testing and sampling of the well as described in Sections 2.2 and 2.3, respectively. While the first well was being tested, the driller moved to a second well and drilled 50 feet into bedrock. When testing was completed at the first well, the driller returned to drill an additional 50 feet and the second well was tested. Drilling and testing proceeded in this manner until each well had been drilled to a depth of about 150 ft into bedrock. Each well was tested three times.

The wells were surveyed by ERM on February 15, 1988 to determine their location coordinates and the elevation of the top of the casing. These data are also presented in Table 1.

## 2.2 HYDROGEOLOGIC TESTING

Hydrogeologic tests were conducted on the test wells to determine the hydraulic properties of the bedrock in the vicinity of each well and the potential yield of each well. These tests included constant-rate pumping tests and step-pumping tests. A brief discussion of the testing is presented below.

### 2.2.1 Constant-Rate Pumping Tests

Constant-rate pumping tests were conducted on each test well following 50 feet of drilling and well development. Two constant-rate tests were performed on each well: one for a 50-foot depth into bedrock, and the other for a 100-foot depth into bedrock. The tests were conducted by temporarily installing a 4-inch diameter submersible pump (powered by a gas generator) in the well and pumping at a constant discharge rate for a short time (generally 2 to 3 hours) while monitoring and recording the drawdown of the water level in the pumping well and nearby observation wells. The volume of water discharged during the tests was measured with a cumulating flow meter and drawdown in wells was recorded using pressure transducers and electronic sounders. After the pump was shut off, the recovery of water levels in the wells was also recorded. These data were analyzed to determine the permeability of the bedrock within the shallow (0-50 feet into bedrock) and intermediate (0-100 feet into bedrock) intervals in the vicinity of each well. The results of these

analyses were also used to design the step-pumping tests. A summary of the data from these tests is given in Table 2.

### 2.2.2 Step-Pumping Tests

After all six wells were completed, the entire open interval of each well was step-tested. The purpose of these tests was to determine the hydraulic properties of the entire open interval as well as to determine the specific capacity of each well at various discharge rates.

These tests were conducted by pumping the well for three successive time periods where the discharge rate was increased at the beginning of each period (or step) and maintained constant for the duration of the step. To provide data that are comparable with the constant-rate tests conducted on the shallow and intermediate intervals of each well, the first step of each step-pumping test had a duration of two hours and a discharge rate similar to that of the earlier tests in the well. Subsequent steps at higher discharge rates were of a duration of about 30 minutes. The drawdown and recovery of water levels in the pumped well and in nearby observation wells was recorded. Similar equipment was used for the step-tests as described above for the constant-rate tests. Table 3 provides a summary of the step-pumping tests.

### 2.3 GROUND-WATER SAMPLING

Samples of ground water were collected from each well subsequent to drilling and testing each 50-foot interval. Prior to sampling, the well was purged a minimum of three volumes of water. Samples from the shallow and intermediate bedrock intervals were retrieved with either a teflon or stainless steel bailer which was lowered to about the midpoint of the open

interval of the well. The bailed water was then carefully poured into the sample vials so that when capped, no air bubbles were allowed to remain in the vials. Composite samples were collected from each well near the end of the step-pumping test conducted on that well. These samples were collected from the flow valve.

All samples were analyzed for volatile organic compounds which included 1,2,3-trichloropropane (TCP). The composite samples from each well were also analyzed for semi-volatile organic compounds. In addition to samples collected for laboratory analysis, the potential accumulation of DNAPL in the well was checked after testing and sampling and before drilling resumed. This was accomplished by lowering a bailer to the bottom of the well and noting if DNAPL had accumulated in or was found as a residue on the bailer.

The bailers were steam cleaned prior to each use, and a separate bailer was dedicated for use at each well. New nylon twine or a similar type material was used for each sample collection.

Personnel from SSP&A collected the samples from the shallow and intermediate bedrock depth intervals of each test well after conducting the constant-rate pumping tests at each well. Samples taken at the end of the step-pumping tests were collected by ERM personnel. In both cases, the samples were labeled by SSP&A, and packed and shipped by ERM.

#### 2.4 WATER-LEVEL MEASUREMENTS

Measurements of the depth to water in the test wells and in the existing monitoring well nests were made on March 17 and 24, 1988. These readings were

subtracted from the measuring point elevation (see Table 1) to give the water-level elevation in each well. These elevations are listed in Table 4.

### 3.0 RESULTS OF INVESTIGATIONS

A brief description of the hydrogeologic setting of the Tyson's site and the results of the analyses of field data bearing on the hydrogeologic conditions in the vicinity of the Tyson's site are presented in the following sections.

#### 3.1 HYDROGEOLOGIC SETTING

The Tyson's site is situated within the Triassic Lowlands Physiographic Province in southeastern Pennsylvania. This physiographic province is composed of sedimentary rocks of Triassic age which include shales, sandstone and arkosic sandstones. These rocks have a general northeast-southwest strike and dip an average of 12 degrees to the northwest. The Stockton Formation, which consists of alternating sandstones, siltstones, and shales, underlies the site. These sediments were deposited in a large basin as coalescing alluvial fans and thus vary widely in character, both laterally and vertically. The Stockton Formation is estimated to be 4,000 feet thick at Norristown and 2,300 feet thick at Phoenixville.

The Stockton Formation has been divided into three members of which the Lower Member directly underlies the site. The Lower Member consists of medium-to-coarse arkosic sandstone and arkosic conglomerates interbedded with finer-grained shales and siltstones. The Lower Member of the Stockton Formation is estimated to be at least 1,000 feet thick in the vicinity of the site (ERM, 1987).

Joints and minor faults are common within the Stockton Formation. Jointing is commonly vertical and occurs perpendicular, parallel and at about

45° to the strike of the bedding. Faults commonly have less than 10 feet of displacement.

The Lower Member of the Stockton Formation is overlain by recent unconsolidated deposits. South of the Conrail railroad tracks these materials consist of undisturbed colluvium and fill material. The colluvium materials consist of clayey sandy silts with fine to coarse gravel more predominant at depth. The thickness of the colluvial deposits varies greatly throughout the site depending on the bedrock topography. These deposits reach a maximum thickness of 31 feet at the site. Fill material overlies the bedrock in the lagoon areas and varies from zero to twenty-five feet in thickness. The fill material consists of silty, gravelly sand, construction debris, and some colluvium.

Floodplain deposits exist underneath the railroad tracks and north to the Schuylkill River. These deposits are as much as twenty-five feet thick and range from sandy clay to sand and gravel in composition. Sand and gravel are more prevalent near the base of these deposits and toward the Schuylkill River. The deposits are more fine grained underneath the railroad tracks and have not been found to exceed 10 feet in thickness.

Ground water occurs within both the unconsolidated deposits and the Stockton Formation in the site vicinity. In general, ground-water flow is toward the Schuylkill River which is the regional discharge point for the area. Flow in the Stockton Formation is primarily through fractures, while flow in the unconsolidated deposits is primarily intergranular. Water-level data in the site vicinity indicate that horizontal and vertical flow is toward

the Schuylkill River. Several well nests adjacent to the river indicate upward flow. Fracture patterns in the Stockton Formation may locally vary the direction of ground water flow. A more detailed description of ground-water gradients is presented in Section 3.3. Testing at the site has shown a fair degree of anisotropy which is attributed to the variable orientation of fractures which occur in the area. Testing also indicates that the permeability of the bedrock decreases with depth most probably as a result of the closing of fractures due to increasing lithostatic pressure.

### 3.2 ANALYSIS OF HYDROGEOLOGIC TEST DATA

As discussed in Section 2.2, pumping tests were conducted on each test well. The analysis and results of the test data are presented in this section.

#### 3.2.1 Constant-Rate Pumping Tests

For each test, plots were prepared of the observed drawdown in the well due to pumping versus time during the tests. The graph on Figure 4 shows that, when plotted on logarithmic coordinates, the early data fall on a straight line having a slope nearly equal to one. This indicates that at early times most of the water discharged from the well is derived from storage within the well (Papadopoulos and Cooper, 1967). Plots of similar form resulted from each test indicating that storage of water in the well has affected the early data during each test.

The test data were therefore analyzed using either the Papadopoulos and Cooper (1967) type-curve method or the generalized straight-line method of Cooper and Jacob (1946). In applying this latter method, corrections were

made to the measured discharge rate to account for wellbore storage effects. For each drawdown measurement, a corresponding formation discharge rate was calculated by subtracting from the measured discharge that portion of discharge derived from water stored in the well. Plots were then made of the specific drawdown against the logarithm of an equivalent time. The specific drawdown is the ratio of the drawdown to the corresponding formation discharge, and the equivalent time is the weighted logarithmic mean of the actual time since the beginning of the test. As noted by Cooper and Jacob (1946), this equivalent time corresponds to the time at which a measured drawdown would have occurred if the entire test was conducted at a constant rate equal to the formation discharge rate corresponding to that particular drawdown measurement.

For wells EW-1, EW-2, EW-3, EW-4, and EW-5, analyses of the test data by the Cooper and Jacob method provided the best estimates of transmissivity for both the shallow (50 feet into bedrock) and intermediate (100 feet into bedrock) depth intervals. Figures 5, 6, 7, 8, and 9 show plots of specific drawdown versus the logarithm of equivalent time for the shallow and intermediate interval tests in these five wells. Also shown on these plots are the slopes of the straight lines drawn through the data and the transmissivities calculated from these slopes.

Analyses of the data from both the shallow and intermediate interval tests of well EW-6 by the Papadopoulos and Cooper (1967) type-curve method provided the most reliable estimates of transmissivity for these intervals. Figure 10 shows the trace of the type curves through the test data, the match points, and the transmissivities calculated. The test of the shallow interval

of well EW-6 was conducted by pumping the well initially at a rate of about 6 gpm. The water level in the well essentially stabilized within 25 minutes of pumping and remained stable except for minor fluctuations. Therefore, after 180 minutes of pumping the discharge rate was increased to 18.5 gpm and the test was continued for another 95 minutes (see Table 2). The data analyzed from this test (see Figure 10) is the additional drawdown caused during the latter pumping period by the about 12.5 gpm increase in the discharge rate from about 6 gpm to 18.5 gpm.

As the plots of the test data (Figures 5 through 10) indicate, the effects of leakage into the tested zone from overlying and underlying water bearing zones, and/or the effects of a constant-head boundary (the river), are apparent in the latter time data from some of the tests.

### 3.2.2 Step-Pumping Tests

Data from the step-pumping tests were also affected by wellbore storage and were corrected using the method described in the previous section. The total transmissivity of each well was determined by applying the generalized straight-line method of Cooper and Jacob (1946) to the drawdown data.

Figures 11, 12, 13, 14, 15 and 16 show plots of specific drawdown versus the logarithm of equivalent time for wells EW-1, EW-2, EW-3, EW-4, EW-5 and EW-6. Data from each step are distinguished in some of the plots. Also shown on these plots are the slopes of the straight lines drawn through the data and the transmissivities calculated from these slopes.

Leakage and/or river boundary effects were also noted in some of the step-test results. In addition, well losses occurred during each test, as noted by the parallel slopes of data from successive steps in some wells. Also, for some wells, data from the second and third steps were not amenable to analysis and the analyses were limited to data from only the first step.

### 3.2.3 Summary of The Test Results

Figure 17 shows the distribution of transmissivity with depth at the test well locations, and Table 5 presents the results of each test. The three transmissivity values shown on Figure 17 represent those calculated for the open borehole at the time of testing. In addition to these values, Table 5 also lists the transmissivity for successive 50-foot intervals in the bedrock. These results show, in general, that the permeability is greatest in the shallow bedrock, and decreases with depth.

The range of transmissivity in the shallow bedrock interval is 6 to 430  $\text{ft}^2/\text{d}$ , and the average transmissivity is 230  $\text{ft}^2/\text{d}$ . Transmissivities determined for the intermediate depth interval range from 23 to 510  $\text{ft}^2/\text{d}$ ; the average is 290  $\text{ft}^2/\text{d}$ . By subtraction, the transmissivity in the interval from 50 to 100 feet into bedrock ranges from 17 to 110  $\text{ft}^2/\text{d}$ , and the average is 62  $\text{ft}^2/\text{d}$ .

Transmissivities for the tested full depth interval (150 feet into bedrock) range from 36 to 530  $\text{ft}^2/\text{d}$ , and the average total transmissivity is 330  $\text{ft}^2/\text{d}$ . By subtracting the results obtained for the first 100 feet into bedrock, the average transmissivity of the interval from 100 to 150 feet into

bedrock is obtained as 39 ft<sup>2</sup>/d, and the range of transmissivity for this interval is from 3 to 90 ft<sup>2</sup>/d.

Based on the results of tests previously conducted in monitoring well nests, SSP&A (1987) had concluded that the bedrock has a high transmissivity on the west side of the area between the site and the Schuylkill River, and a low transmissivity on the east side of this area. The results of the recent testing in the test wells do not support this earlier conclusion. For example, well EW-2 in the "high transmissivity" area, has a relatively low transmissivity. On the other hand, well EW-6 in the "low transmissivity" area has a relatively high transmissivity. Also, earlier tests had indicated the transmissivity in well nest 10 to be 560 ft<sup>2</sup>/d (SSP&A, 1987), whereas the recent tests indicate the transmissivity in the nearby test well EW-2 to be 97 ft<sup>2</sup>/d.

This comparison with the previous results indicates that rather than having areas of different transmissivity, the transmissivity in a given well location depends on the degree of fracturing at that location and the number of fractures intercepted by the well. In general, it is apparent that the bedrock has an average transmissivity of about 500 ft<sup>2</sup>/d with the permeability decreasing with depth.

### 3.3 WATER-LEVEL DATA

Water-level data were analyzed to determine the ground-water flow patterns and natural hydraulic gradients within the bedrock aquifer underlying the Tyson's site. These data included recent water-level measurements (Table 4) and data previously compiled by ERM (1987).

The data compiled by ERM consisted of sets of water-level elevations for the bedrock monitoring well nests (see Figure 2), where each set was taken on a given day during the time period from March 1986 to July 1987. Within this time interval, a "common period" was identified as April 8, 1987 to July 1, 1987 where, in each set of measurements, a water-level measurement was reported for each of the bedrock wells in the well nests. These data, which included 12 complete sets of measurements, were time-weighted to obtain the average water-level elevation in each well.

Water-level elevations from two staff gages in the river have also been reported (ERM, 1987). These data included six dates from April 27, 1987 to July 1, 1987 when a water-level elevation was reported for both staff gages. 4

Figure 18 shows contours of the time-weighted average water-level elevations in the shallow bedrock monitoring wells for the period from April 8, 1987 to July 1, 1987. The average water-level elevation of the river from April 27, 1987 to July 1, 1987 from measurements at the staff gages was utilized in drawing these contours. Time-weighted average water-level contour maps, corresponding to the same period, were also prepared for the intermediate and deep bedrock intervals. The flow patterns in these intervals are similar to those in the shallow bedrock intervals.

Water-level contour maps for the shallow, intermediate and deep bedrock intervals were also prepared for each of the two recent water-level measurements (see Table 4). In preparing these maps, the water-level measurements in the six new test wells were assumed to represent the shallow bedrock interval, which has the highest transmissivity. Comparison of these

single measurement water-level maps with the corresponding time-weighted average water-level maps did not show any significant differences.

Ground water generally flows toward the river with an average horizontal hydraulic gradient of 0.040. Although there are local variations in the direction and magnitude of the gradients in each interval, the average gradient is 0.040 in the shallow interval, 0.030 in the intermediate interval, and 0.040 in the deep interval.

Vertical gradients exist over the entire site between wells completed at varying depths. Strong upward gradients between the deep and shallow wells occur in well nests 3, 4, 5, 6, 8, 9 and 11, and range from 0.032 to 0.132 with an average of 0.090, about 2.3 times the average horizontal gradient.<sup>4</sup> Upward gradients are also apparent in well nest 10 as the water levels in wells 10XD and 10I are higher than that in well 10S; however, well 10D has a lower water level than the other three wells at this well nest. The open interval of well 10D has a very low transmissivity (SSP&A, 1987); thus, it is possible that the water level in the well does not accurately reflect the potentiometric level of the bedrock aquifer at this depth interval. Downward vertical gradients exist between the shallow and deep wells at well nests 7 and 12, and average 0.007.

### 3.4 WATER-QUALITY DATA

Preliminary results of the samples from the test wells were provided to SSP&A by ERM. The results for four specific compounds are presented in Table 6.

Figure 19 shows the spatial distribution of TCP found in the test wells. Samples from well EW-6 have the lowest concentrations of TCP, indicating that this well is located near the eastern limits of the area of ground-water contamination. Among the other five wells, well EW-2 has the lowest TCP concentration (0.056 mg/L) in the shallow bedrock interval (0-50 feet into bedrock) and the highest TCP concentration (495 mg/L) for the full sampled interval (0-150 feet into bedrock). Within the shallow bedrock interval, the highest concentrations of TCP are in wells EW-3, EW-4 and EW-5, indicating that in shallow bedrock the most contaminated ground water occurs in the area between wells EW-3 and EW-5, immediately downgradient from the site. Except for well EW-6, samples from the full open intervals of the wells (0-150 feet into bedrock) have the highest concentrations of TCP, indicating that the highest levels of contamination occur in the deeper-bedrock interval (100-150 feet into bedrock) where the permeability is the lowest.

No DNAPL was found in or on the bailers which were lowered to the bottom of each well subsequent to drilling, development, hydraulic testing, and sampling of the shallow and intermediate intervals. The wells were also checked for presence of DNAPL prior to conducting the step-pumping tests (about three weeks after drilling and development of the last well was completed). Again, DNAPL was not found. The wells were checked again by ERM on April 28, 1988. At that time, DNAPL of a thickness of 0.31 foot was found in one well, well EW-4.

#### 4.0 DESIGN OF RECOVERY SYSTEM

##### 4.1 METHODS

To determine the number and location of extraction wells for controlling the movement of contaminants from the Tyson's site, a numerical, three-dimensional simulation model of the bedrock aquifer was developed. The model was based on a computer code developed by the U.S. Geological Survey (Trescott 1975, and Trescott and Larson, 1976) to simulate ground-water flow in three dimensions. The code uses the finite difference method to solve the partial differential equation of ground-water flow.

Figure 20 shows the extent of the modeled area and the boundary conditions for the model. The modeled area extends 2,630 feet in the east-west direction and 1,900 feet in the north-south direction. The area covers approximately 3,000 feet along the Schuylkill River and extends as much as 2,600 feet south of the Schuylkill River.

The finite difference grid developed for the model has 70 rows and 90 columns. The grid has variable spacing but the majority of the grid in the immediate vicinity of the site has a spacing of 25 feet. The row-direction of the grid is oriented along the approximate strike (N70E) of the Lower Member of the Stockton Formation. This orientation allows simulation of potential anisotropy in the horizontal direction.

The ground-water environment was divided into eight layers which represent a total thickness of 265 feet below the approximate level of the water table within the floodplain deposits. The three bottom layers were each 50 feet thick, the next four layers were 25 feet thick and the uppermost layer

was 15 feet thick. Layers 3 through 7 (see Table 7) correspond closely to the intervals drilled and tested during the field investigation.

To avoid underestimating the rate of ground-water discharge that would be necessary to capture northward moving contaminated ground water, a very conservative approach was used in assigning transmissivities to the modeled bedrock intervals. For the three upper 50-foot intervals of the bedrock (0-50, 50-100 and 100-150 feet into bedrock), the transmissivities assigned to the model were calculated as follows. For each interval, any test-determined transmissivity (see Table 5) which was less than one-third of the highest value for the interval was discarded and the remaining values were averaged. The resulting averages were 330 ft<sup>2</sup>/d for the shallow interval (50 feet into bedrock), 70 ft<sup>2</sup>/d for the intermediate interval (50 to 100 feet into bedrock) and 65 ft<sup>2</sup>/d for the deep interval (100 to 150 feet into bedrock). As an additional safety factor, these averages were increased by about 10 percent and transmissivities of 360 ft<sup>2</sup>/d, 80 ft<sup>2</sup>/d and 70 ft<sup>2</sup>/d, respectively, were assigned to these three bedrock intervals. The modeled lower 100 feet of the bedrock were arbitrarily assigned a transmissivity of 40 ft<sup>2</sup>/d. The floodplain deposits were assigned a transmissivity of 670 ft<sup>2</sup>/d, based on an assumed permeability of 45 ft/d, and unconsolidated deposits outside the floodplain, a transmissivity of 120 ft<sup>2</sup>/d, based on an assumed permeability of 8 ft/d.

Table 7 summarizes the distribution of these transmissivities among the model layers and the corresponding permeability for each layer. Layers 7 and 6 represent the bedrock interval from approximately 30 to 80 feet below ground surface (0 to 50 feet into bedrock), layers 5 and 4 the interval from

approximately 80 to 130 feet below ground surface (50 to 100 feet into bedrock), and layer 3 the interval from approximately 130 to 180 feet below ground surface (100 to 150 feet into bedrock). Layers 1 and 2 represent an additional 100 feet of bedrock below the 150-foot interval. It was assumed then beyond this depth the bedrock does not have any significant permeability. Layer 8 represents the saturated portion of the floodplain deposits near the Schuylkill River and of the colluvium and fill material south of the railroad tracks.

The Schuylkill River was simulated as a constant head boundary condition in the uppermost layer (see Figure 20). The eastern and northern boundary of the modeled area was simulated as a no flow boundary. The western and southern boundaries were simulated as variable head boundaries in all layers to create an average hydraulic gradient of 0.040 foot per foot toward the river. This is the average gradient measured in the field as discussed in Section 3.0. Outside the area covered by the river, a recharge rate of 10 inches per year was assigned to the uppermost layer.

Pumpage was applied to layers 3 through 7 in three different ways. The various pumping conditions are described in Section 4.2. Steady state conditions were simulated in all scenarios.

The output from the three-dimensional ground-water flow model was used in conjunction with a particle tracking program developed by SSP&A (Larson et al., 1987) to estimate the zones of capture for various pumping scenarios. The particle tracking program uses the steady state head distribution from the flow model to calculate the Darcian velocity of a given particle and moves the

particle forward incrementally until it reaches either an extraction well, the water table, or a model boundary. Particles are started at specific elevations (relative to mean sea level) along a uniformly spaced grid in a horizontal plane. The extent of the zone of capture at any particular elevation is delineated by plotting the starting locations of all particles which are captured by the extraction wells. Pathlines of ground-water flow are determined by plotting the coordinates of a specific particle at different times as it moves incrementally from one point to another.

#### 4.2 ANALYSIS OF THE PROPOSED RECOVERY SYSTEM

The methods described in Section 4.1 were used to delineate the extent of the zones of capture and identify pathlines of ground-water flow for various extraction well scenarios. Several scenarios were evaluated which focused on the number of pumping wells, the total pumping rate, the interval at which the pumping occurs and various anisotropic conditions. Simulations were made with six, twelve and thirteen extraction wells. Total pumping rates were varied between 140 gpm and 600 gpm. Intervals pumped, referenced to mean sea level, included 1) from 45 feet to -105 feet, pumping the uppermost 150 feet of bedrock; 2) from 45 feet to -5 feet, pumping the uppermost 50 feet of bedrock; and 3) from -5 feet to -105 feet, pumping the interval of 50 to 150 feet below the top of the bedrock (see Figure 21). Simulations were made for both isotropic and anisotropic conditions. Vertical anisotropy of 10 to 1 (ratio of horizontal to vertical permeability) and a horizontal anisotropy of 10 to 1 (ratio of permeability parallel to strike to permeability perpendicular to strike) were used in some simulations. The transmissivity distribution shown in Table 7 was used in all pumping

scenarios; for horizontally anisotropic cases this distribution was used for the direction parallel to the strike.

Based on the analysis of the various scenarios, a 13-well recovery system is proposed. The total pumping rate of the recovery system is 350 gpm. The wells in the recovery system are completed 150 feet into the bedrock. The proposed system will use the six existing test wells EW-1 through EW-6. Seven new extraction wells will be installed as shown on Figure 22. If wells installed adjacent to the existing wells EW-2 and EW-5 indicate higher transmissivities than those indicated by the tests on these two wells, these two wells will be replaced to provide a more even distribution of the discharge rate from each well. 4

The lateral extent of the zone of capture for the 13-well recovery system is also shown on Figure 22; this represents the lateral extent of the area of capture at the top of the bedrock (top of layer 7). The extent of the capture zones for deeper bedrock intervals is similar and indicates that all northward moving ground water, from the top of the bedrock to 100 feet below the pumping interval (the entire modeled interval), is captured by the extraction well system. Under steady-state conditions, about 8 percent, or about 30 gpm, of the total pumpage of 350 gpm is water induced from the river; the remaining 320 gpm is water flowing toward the river upgradient from the line of extraction wells.

In all scenarios simulated, 12- or 13-well recovery systems provided complete capture at a total extraction rate lower than that required for six-well recovery systems. For total capture, a 12-well recovery system also

required a higher discharge rate than that for a 13-well recovery system. Thus, a 13-well recovery system is more effective. Various total pumping rates were utilized and calculations of the zone of capture were made for several depths or elevations (horizontal planes). It was found that, with the 13-well system, a pumping rate of 350 gpm resulted in complete capture in all tracking planes. In general, if complete capture was obtained in layer 7, the uppermost bedrock layer, then complete capture occurred down to a depth of 250 feet below the top of the bedrock.

Scenarios which involved extraction wells pumping from different open intervals were also simulated. In addition to the scenario where the uppermost 150 feet of bedrock was open to the wells (referred to here as the base case), scenarios were evaluated where 1) only the uppermost 50 feet of bedrock (elevation of from 45 to -5 feet) was open to the wells, and 2) the interval from 50 to 150 below the top of bedrock (elevation of from -5 feet to -105 feet) was open to the wells (see Figure 21). For each of these scenarios, the pumping rate for the extraction wells was equal to the pumping rate for the base case multiplied by the ratio of the transmissivity of the open interval for that scenario to the transmissivity of the open interval for the base case. Thus, the pumping rate for the first scenario was 70 percent of the rate for the base case, and the pumping rate for the second case was 30 percent of the rate for the base case. These scenarios were evaluated to examine the feasibility of pumping moderately contaminated water (about 100 ppm TCP) at a moderate rate, or the feasibility of pumping highly contaminated water (greater than 1,000 ppm TCP) at a relatively small rate.

In all simulations, the two scenarios described above provided less extensive zones of capture than the comparable simulation of the base case. Pumping of the interval from 50 to 150 feet below the top of the bedrock produced the least extensive zone of capture.

The final 13-well recovery system was based on a ground-water environment with no horizontal or vertical anisotropy. Making the vertical permeability smaller than the horizontal permeability improves the ability of the recovery system to capture contaminated ground water. This is because the extraction wells draw less water from the Schuylkill River and more water from the bedrock when the vertical resistance to flow is increased. Thus, all simulations completed with no vertical anisotropy represent worst case scenarios in terms of ground-water capture. In terms of horizontal anisotropy, a 10-fold decrease in permeability in a direction perpendicular to the strike of the bedding has only a small effect on the extent of the capture zones.

Figure 23 shows the computed steady-state potentiometric surface at the top of the bedrock during the operation of the proposed 13-well recovery system. Also shown on this figure are ground-water pathlines. Figure 24 shows the computed potentiometric surface and ground-water flow pathlines along a cross-section passing through the mid-point between proposed wells EW-11 and EW-12. (See Figure 23 for alignment of cross-section).

Table 8 presents the proposed initial discharge rates and the estimated drawdowns and pumping lifts for the proposed 13-well recovery system. Although the total discharge rate of 350 gpm was derived on the basis of an

average uniform transmissivity for the bedrock, the discharge rate for individual extraction wells will be governed by the transmissivity of the bedrock near the extraction well. The total discharge was, therefore, distributed among the 13 extraction wells in accordance with the transmissivity near each well. For the existing six wells, the test determined transmissivity was used for this purpose. For the proposed new seven wells, the transmissivity was estimated from those in adjacent existing wells.

After the proposed new seven wells are installed and tested, adjustments will probably be needed to the initial discharge rates presented in Table 8. Adjustments to the discharge rates will probably also be needed periodically during the operation of the system based on the results of the monitoring program presented below.

Based on these proposed initial discharge rates and the TCP concentrations measured in the composite samples from the existing six wells, the initial concentration of TCP in the influent to the treatment plant is estimated to be about 150 mg/L. For this estimate, the concentration of TCP in the proposed new seven wells was estimated from the TCP concentrations in adjacent existing wells.

#### 4.3 MONITORING PROGRAM

The performance of the 13-well recovery system will be monitored through the use of existing monitoring wells and six proposed new shallow monitoring wells. The location of the proposed monitoring wells and the 13 extraction wells are shown on Figure 25. The proposed shallow monitoring wells are to be

located approximately midway between existing and proposed extraction wells where there are no existing monitoring well clusters. The proposed shallow monitoring wells will be completed approximately fifty feet into the bedrock and will be used to measure water levels. The existing monitoring well clusters numbers 7, 11, 8 and 10 will be measured in conjunction with the proposed monitoring wells. The extraction wells will also be equipped with an access pipe extending below the pump for measuring the water level in the wells. It is recommended that water levels be measured monthly during the first year of system operation and quarterly thereafter.

The proposed and existing bedrock monitoring wells should also be monitored for water quality. However, because of the proximity of the recovery wells to the Schuylkill River, monitoring the ability of the extraction system to capture all chemicals migrating from the Tyson's site will be difficult. Nevertheless, chemical concentrations determined between and at extraction wells will provide important information on the variability of water quality along the line of the recovery system. The proposed and existing bedrock monitoring wells should be sampled annually and analyzed for volatile and semi-volatile organics.

Monitoring of water quality will also be required for the influent to and effluent from the treatment plant. These data will provide information needed for the operation of the treatment plant and will also provide a data base for estimating the mass of contaminants removed by the recovery system. The frequency of monitoring the quality of influent and effluent will depend on the operating requirements of the treatment plant.

#### 4.4 A PROPOSED INITIAL RECOVERY SYSTEM

Recent water-quality data indicate the presence of TCP in the intake of the Pennsylvania American Water Company located about 2,000 feet downstream of the site. Although the measured concentrations are very low, in the order of 2 ug/L, their occurrence is of concern to the water company and to CIBA-GEIGY. The recovery system proposed above will capture contaminated ground water discharging into the river and thus eliminate the contamination in the river water. However, under the schedule stipulated in the Partial Consent Decree, the proposed system will not be operative until September 1989.

As an initial measure that may be implemented quickly and that may alleviate most, if not all, of the contamination in the Schuylkill River, ERM proposed a partial recovery system designed to intercept most of the contaminated ground water within the upper 50 feet of the bedrock. The ground water recovered by such a system will be treated using a mobile temporary treatment plant. According to ERM, up to 200 gpm of water can be treated by such a temporary treatment plant.

The most contaminated ground water within the upper 50 feet of the bedrock lies in the area that extends from well EW-3 to about the midpoint between wells EW-5 and EW-6. The numerical model developed for designing the total recovery system was used to evaluate a partial recovery system discharging 200 gpm from seven wells located in this area. For this evaluation the proposed new wells EW-10, EW-11, EW-12 and EW-13 were assumed to be open to only the upper 50 feet of the bedrock, whereas the existing wells EW-3, EW-4 and EW-5 were left open to 150 feet of bedrock.

Figure 26 shows the capture zone of this partial recovery system. This zone represents the area of capture at the top of the bedrock (top of layer 7). Similar capture zones are also developed in deeper horizons of the bedrock. However, travel times from deeper horizons to the new extraction wells open to the upper 50 feet of bedrock will be longer than those to the existing wells which penetrate 150 feet into bedrock. At the time of the implementation of the total recovery system, the four new wells would be deepened to 150 feet into bedrock.

Figure 27 shows the computed steady-state potentiometric surface at the top of the bedrock during the operation of the proposed 7-well initial recovery system. Also shown on this figure are ground-water pathlines. Figure 28 shows the computed potentiometric surface and ground-water flow pathlines along a cross-section passing through the mid-point between proposed wells EW-11 and EW-12. (See Figure 27 for alignment of cross-section).

Table 9 presents the proposed discharge rates and the estimated drawdowns and pumping lifts for this initial recovery system. Based on these discharge rates and average concentrations of TCP in the open intervals of each well, the initial concentration of TCP in the influent to the temporary plant is estimated to be about 45 mg/L. However, as ground water with higher concentrations of TCP begins to move into the wells from deeper horizons of the bedrock, the TCP concentration in the influent would be expected to increase.

## 5.0 FINDINGS AND CONCLUSIONS

The field investigations and model analyses performed to design the ground-water recovery system at the Tyson's Site lead to the following findings and conclusions:

- . The specific capacities of the completed wells ranged from 0.11 to 2.46 gpm/ft. Four of the wells had a specific capacity greater than 1.6 gpm/ft.
- . The transmissivity of the entire tested bedrock interval ranged from 36 to 530 ft<sup>2</sup>/d. In four of the tested wells the transmissivity was greater than 340 ft<sup>2</sup>/d. The uppermost 50 feet of bedrock is the most permeable interval and in four of the test wells this interval had transmissivity values in the range of 190 to 430 ft<sup>2</sup>/d. Based on these results, the average transmissivity of the bedrock aquifer is estimated to be about 500 ft<sup>2</sup>/d.
- . Water-quality samples collected during testing indicate that TCP is by far the most prevalent chemical. Other chemicals at low concentrations were total xylenes, ethylbenzene, and toluene. Concentrations of the compounds measured generally increase with depth. TCP concentrations for the entire interval drilled range from as low as 0.0016 mg/L at EW-6 to 495 mg/L at EW-2. Wells EW-3, EW-4, and EW-5 had very similar concentrations ranging from 181 to 190 mg/L.
- . A 13-well recovery system pumping at a rate of 350 gpm will effectively intercept contaminated ground water discharging into the



Schuylkill River. The extraction wells for the system should be drilled 150 feet into bedrock.

- . Six shallow monitoring wells should be placed midway between extraction wells in order to monitor the performance of the extraction system.
- . A 7-well initial recovery system pumping at a rate of 200 gpm could be implemented quickly to intercept most of the contaminated ground water in the upper 50 feet of the bedrock, and may alleviate contamination in the Schuylkill River.

4

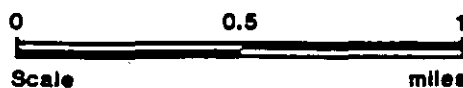
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**FIGURES**

**FIGURES**

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Basemap from U.S. Geologic Survey 7.5 minute series (topographic)  
Norristown quadrangle Pennsylvania, 1966-Photorevised 1983

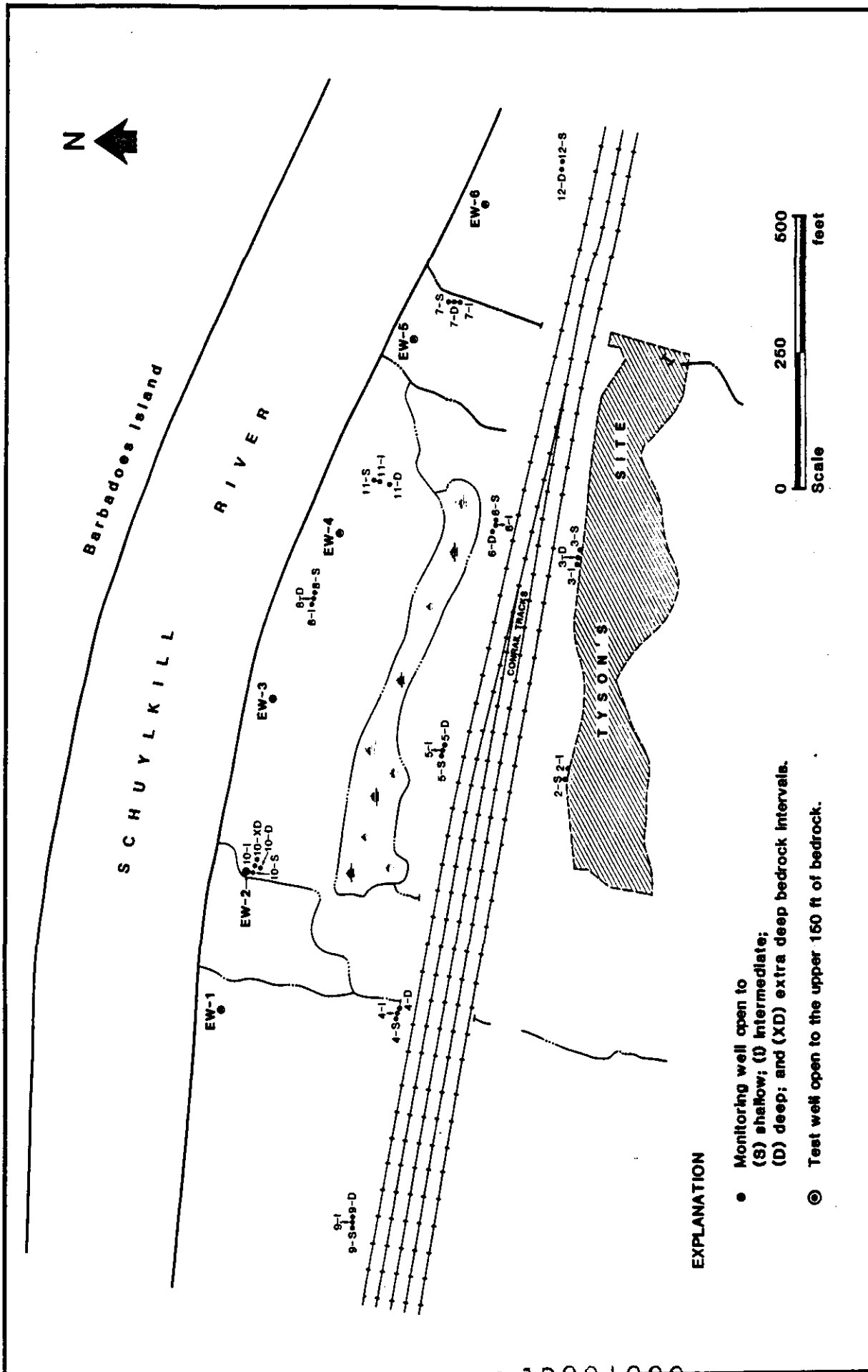


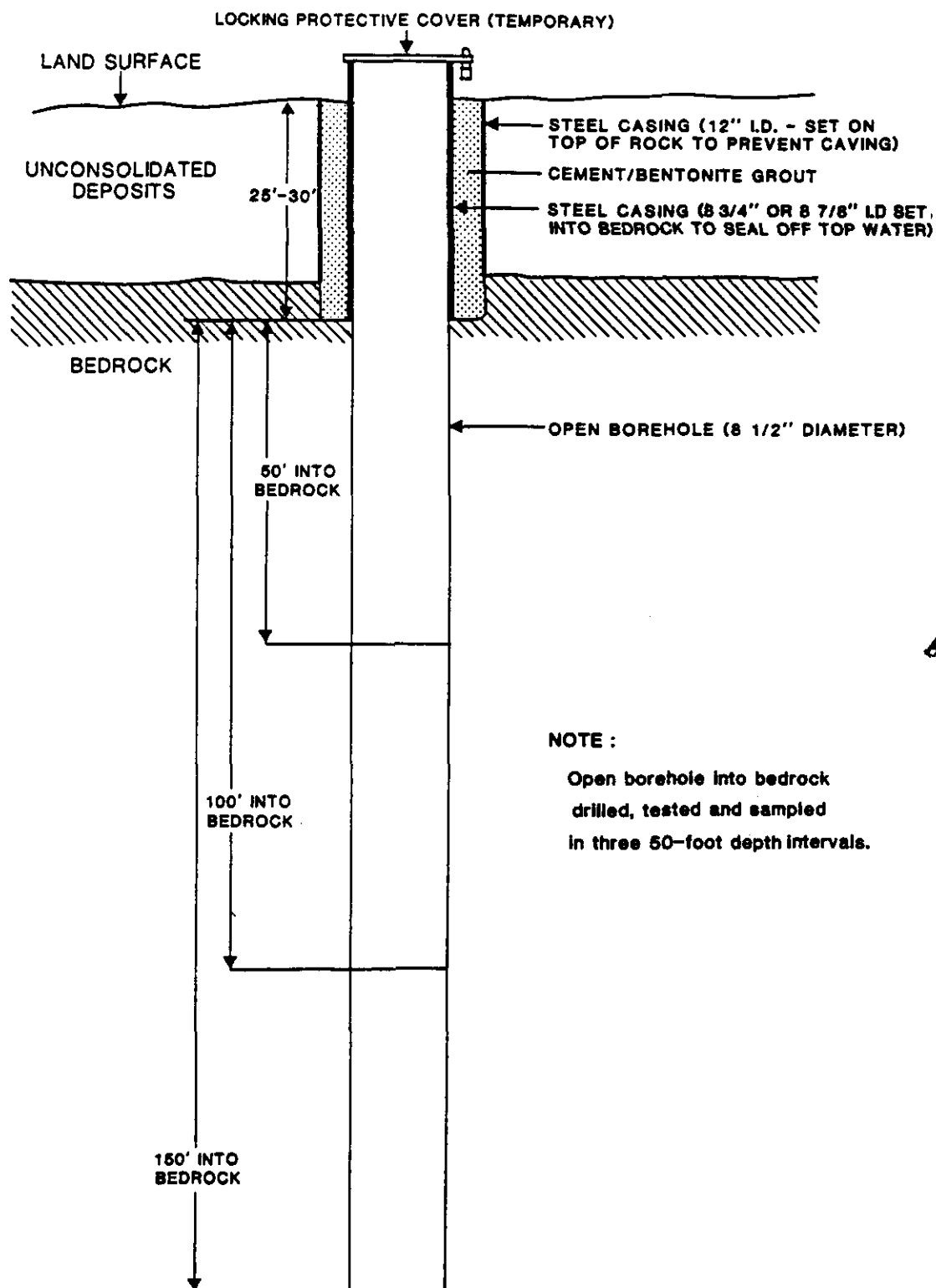
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LOCATION OF TYSON'S SITE

FIGURE  
1

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**NOTE :**

Open borehole into bedrock drilled, tested and sampled in three 50-foot depth intervals.



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SCHEMATIC DESIGN  
OF A TYPICAL TEST WELL

FIGURE  
3

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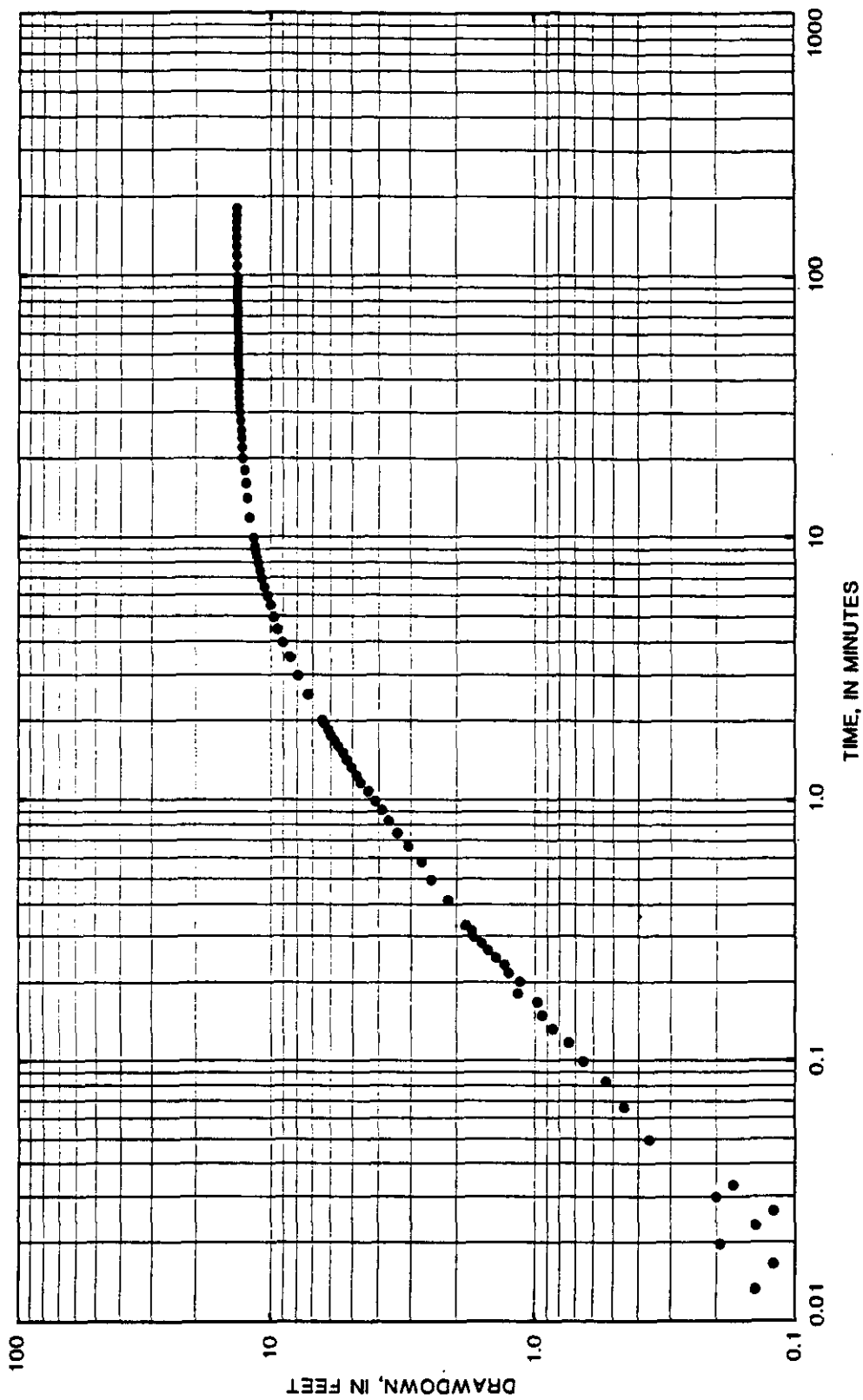


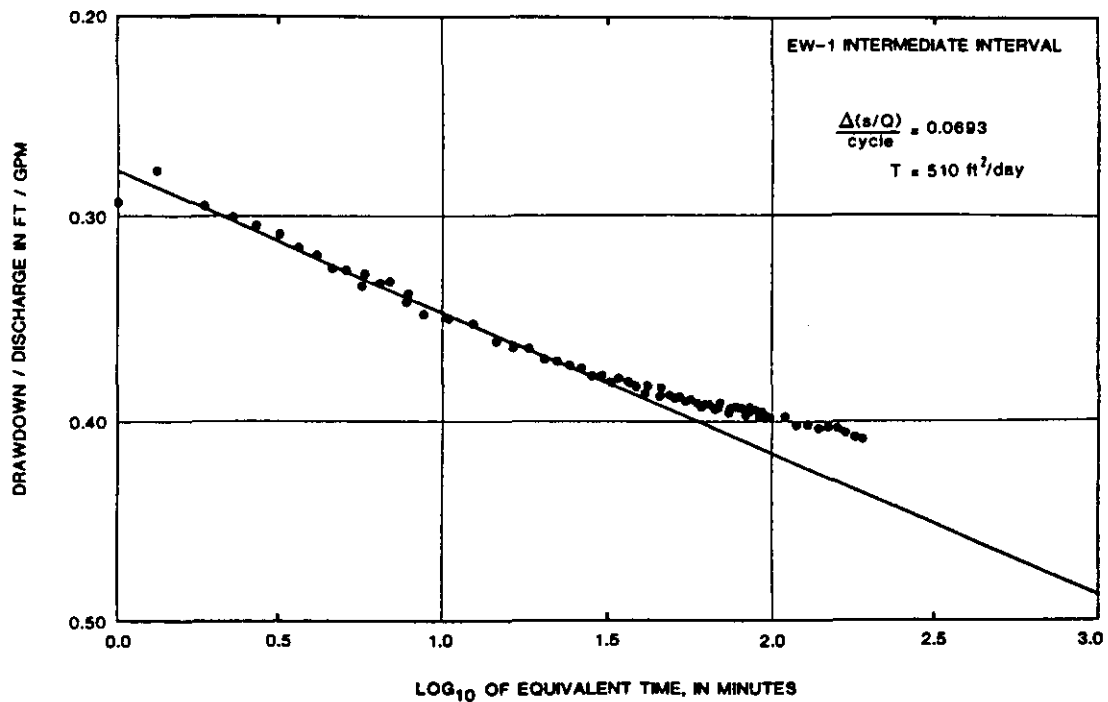
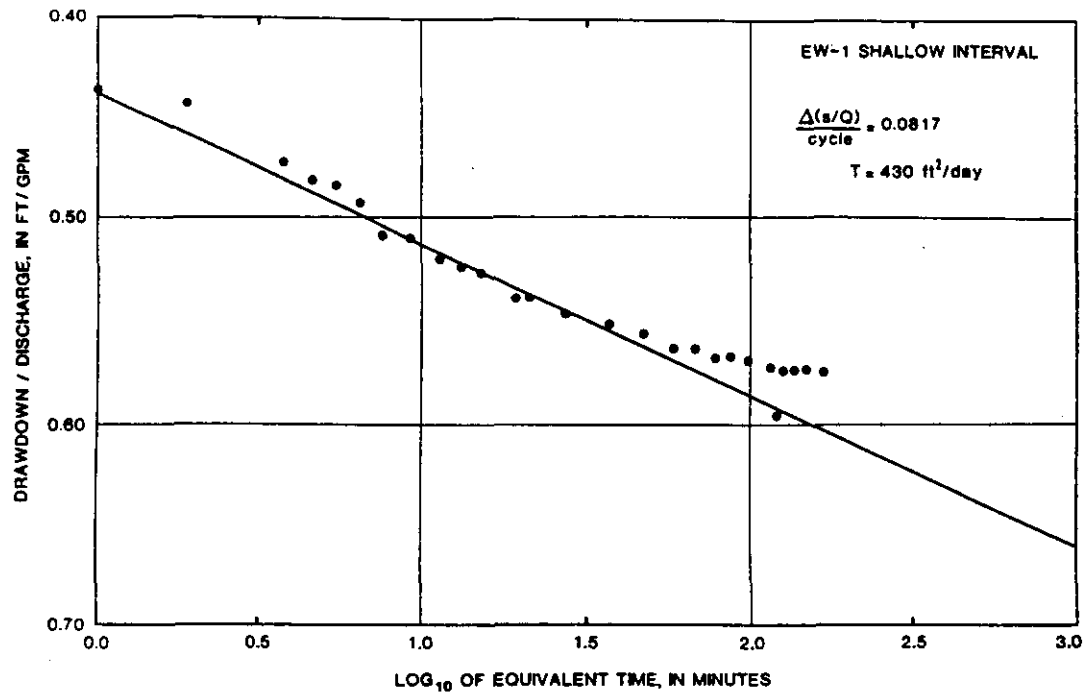
FIGURE  
4

EW-3 INTERMEDIATE BEDROCK INTERVAL CONSTANT-RATE TEST



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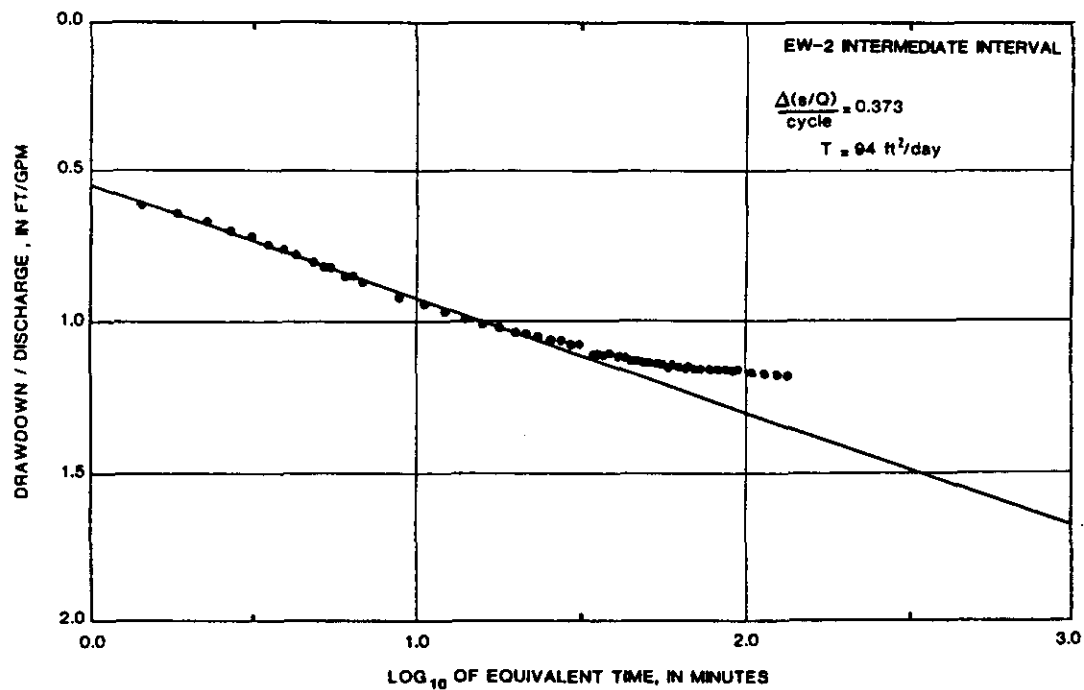
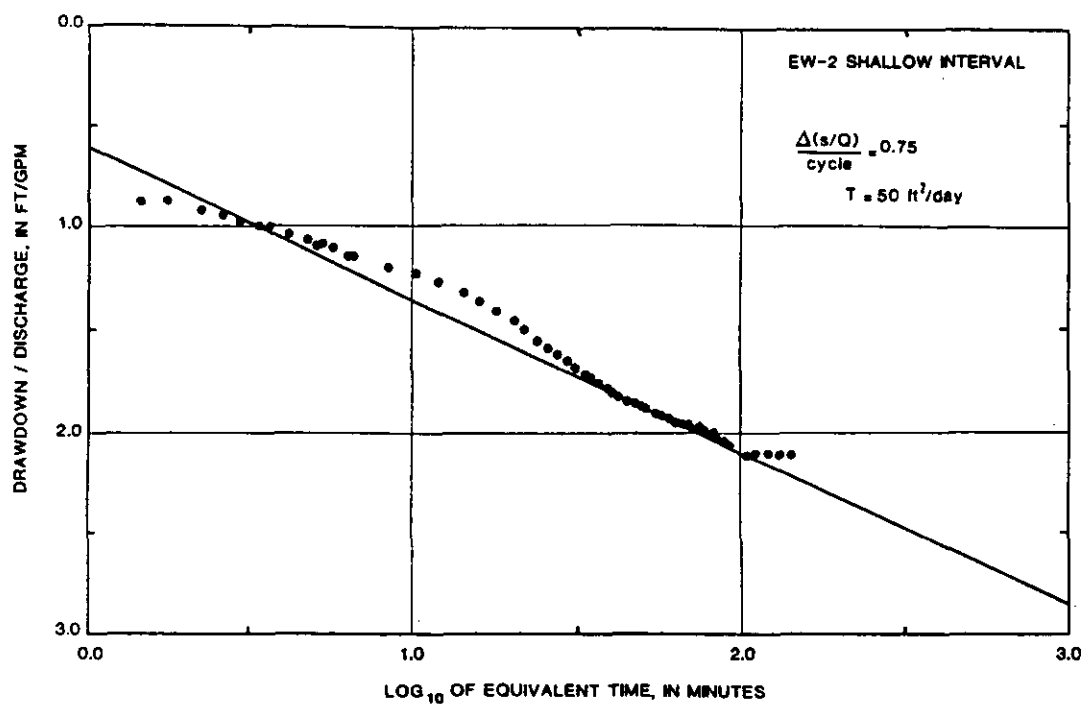


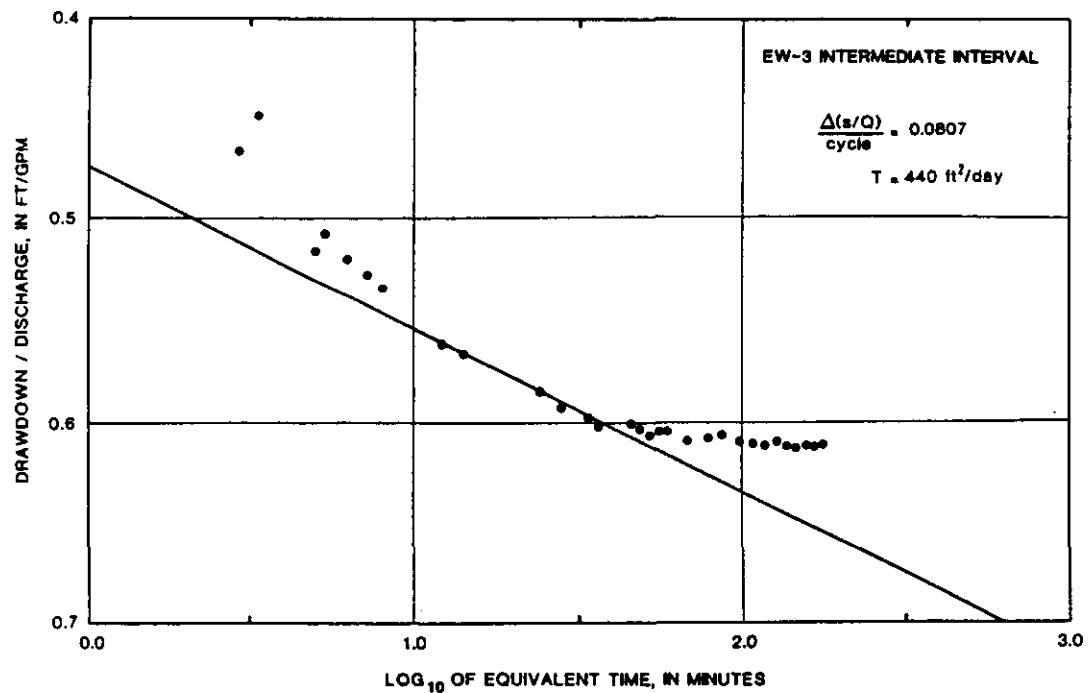
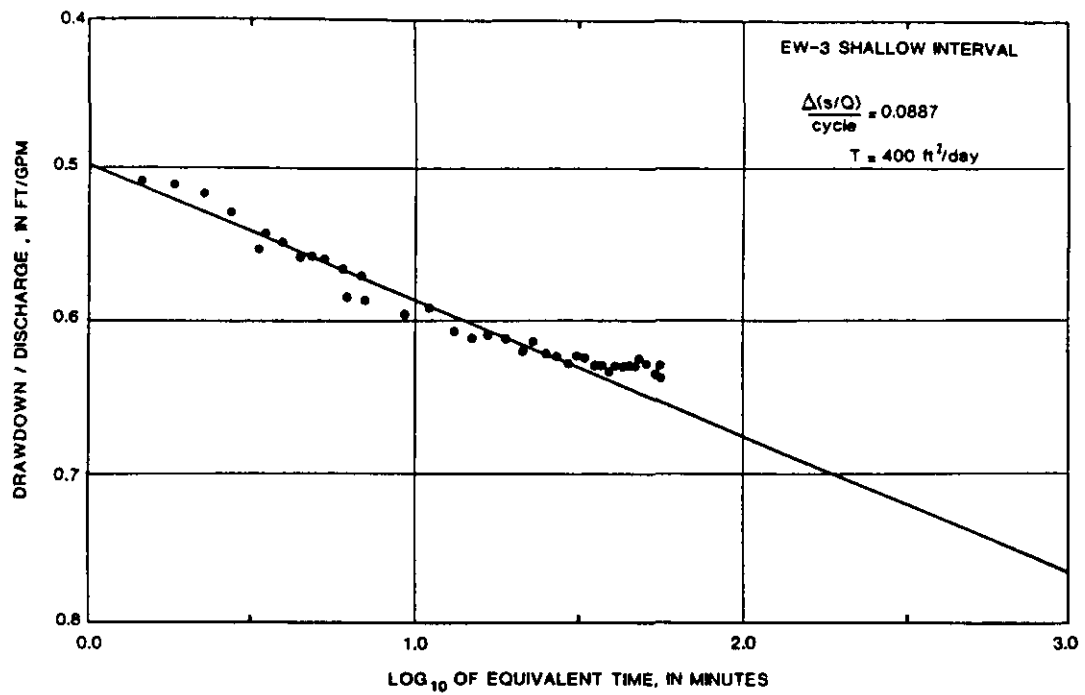
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ANALYSIS OF CONSTANT-RATE TEST DATA,  
WELL EW-1

FIGURE  
5

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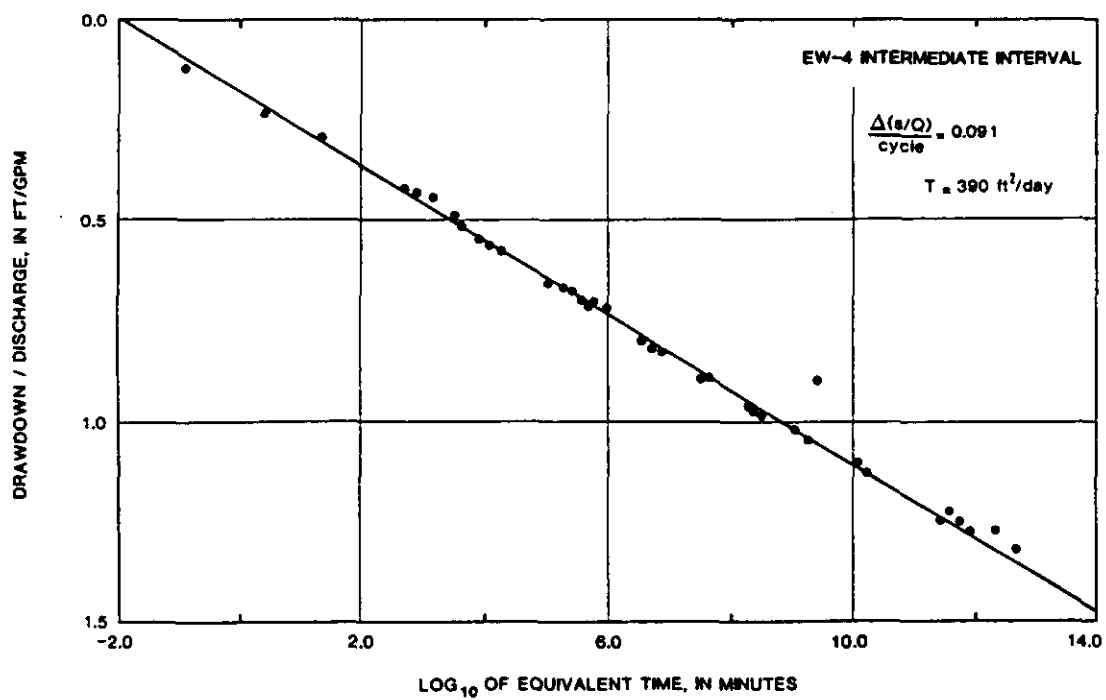
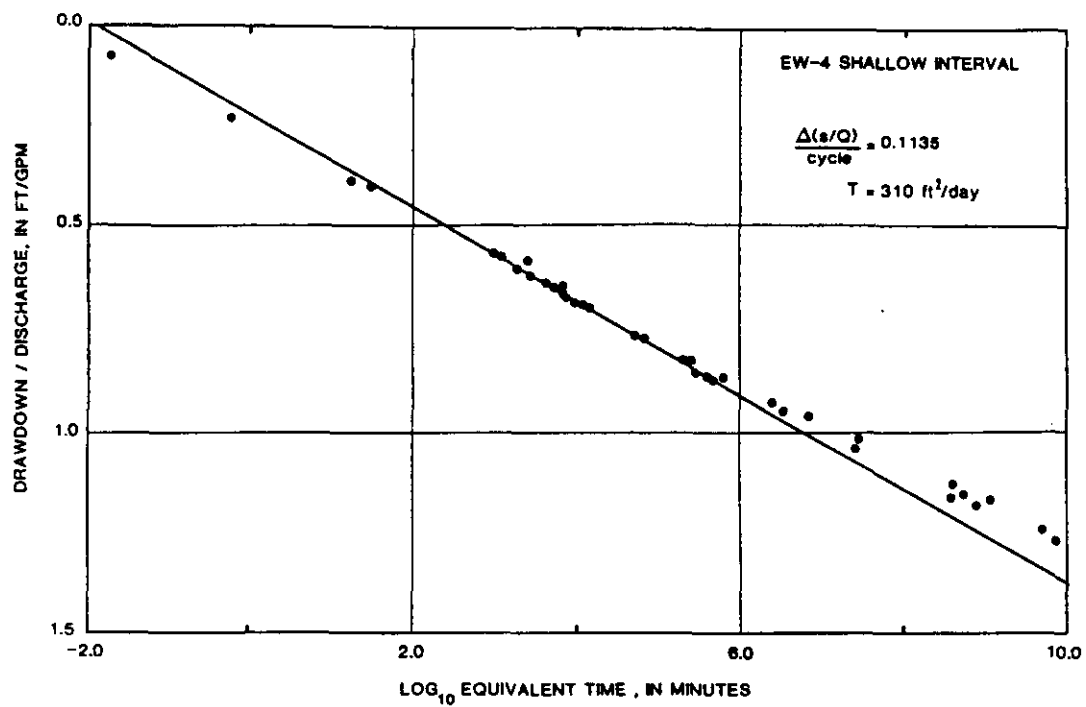


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ANALYSIS OF CONSTANT-RATE TEST DATA,  
WELL EW-3

FIGURE  
7

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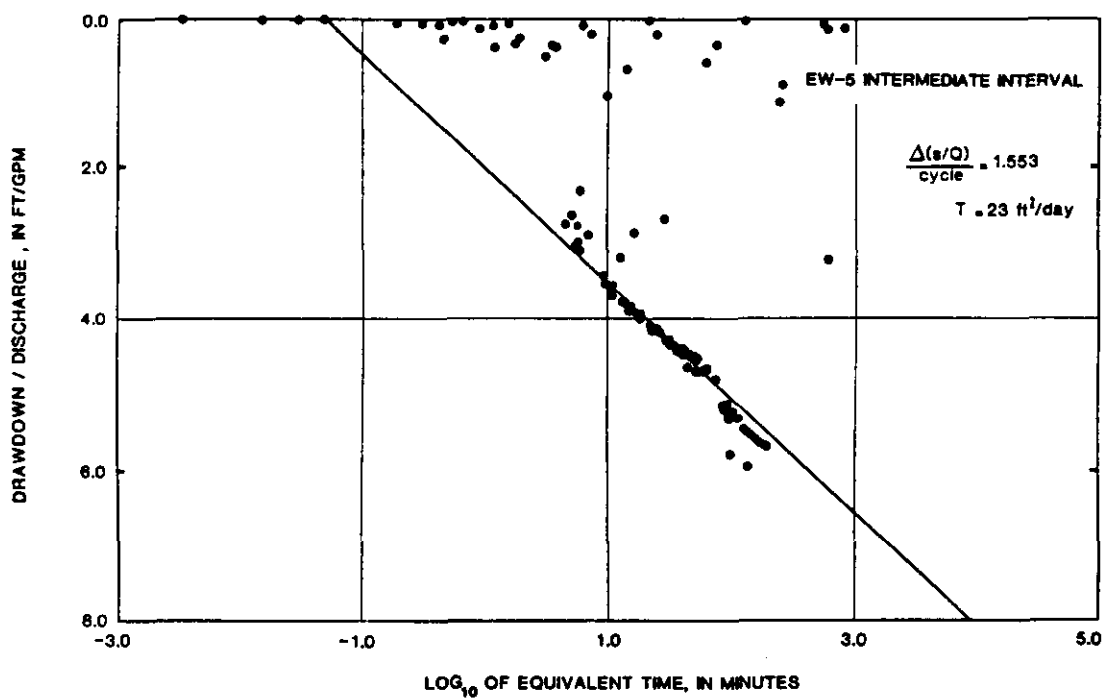
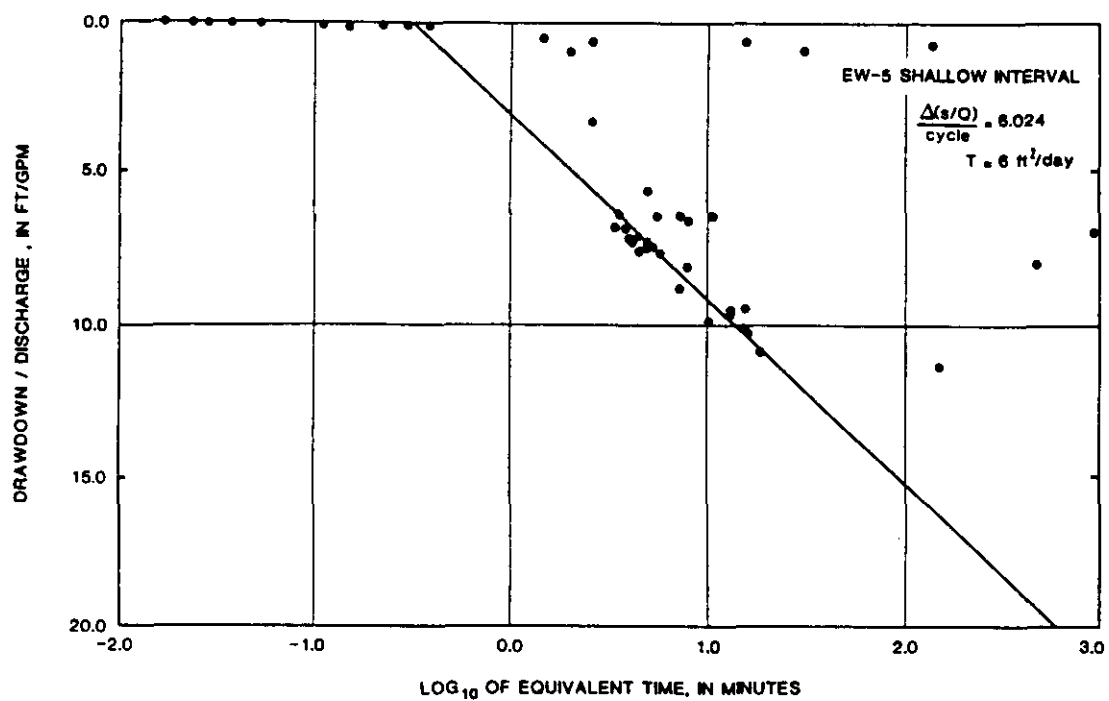


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ANALYSIS OF CONSTANT-RATE TEST DATA,  
WELL EW-4

FIGURE  
8

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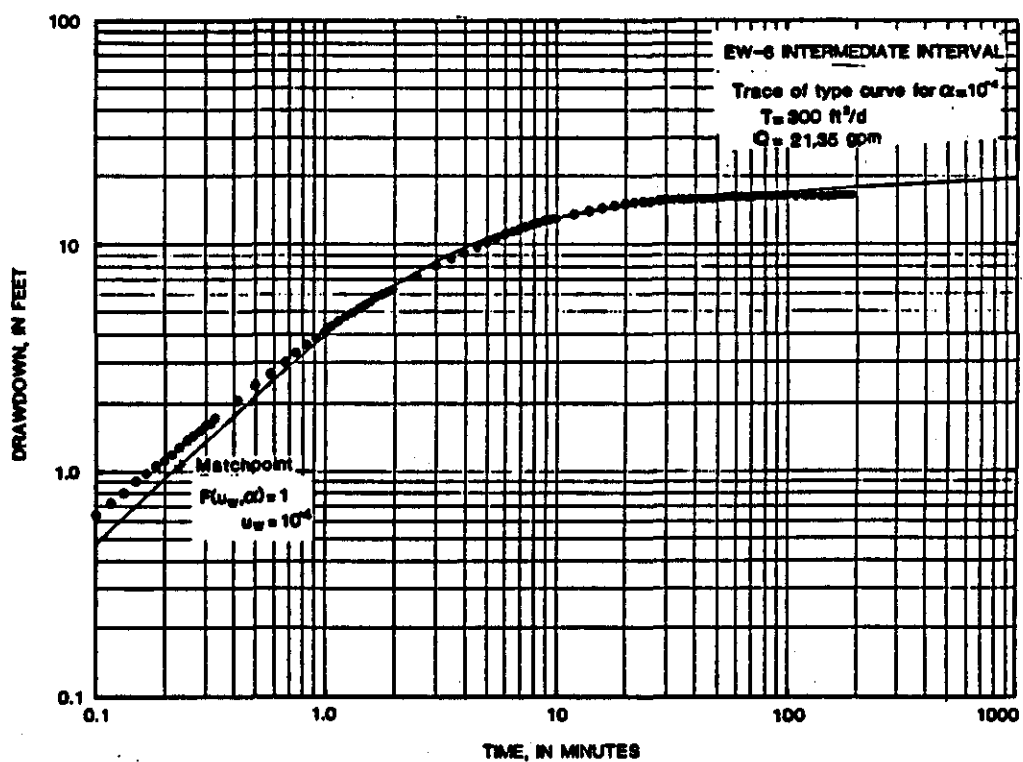
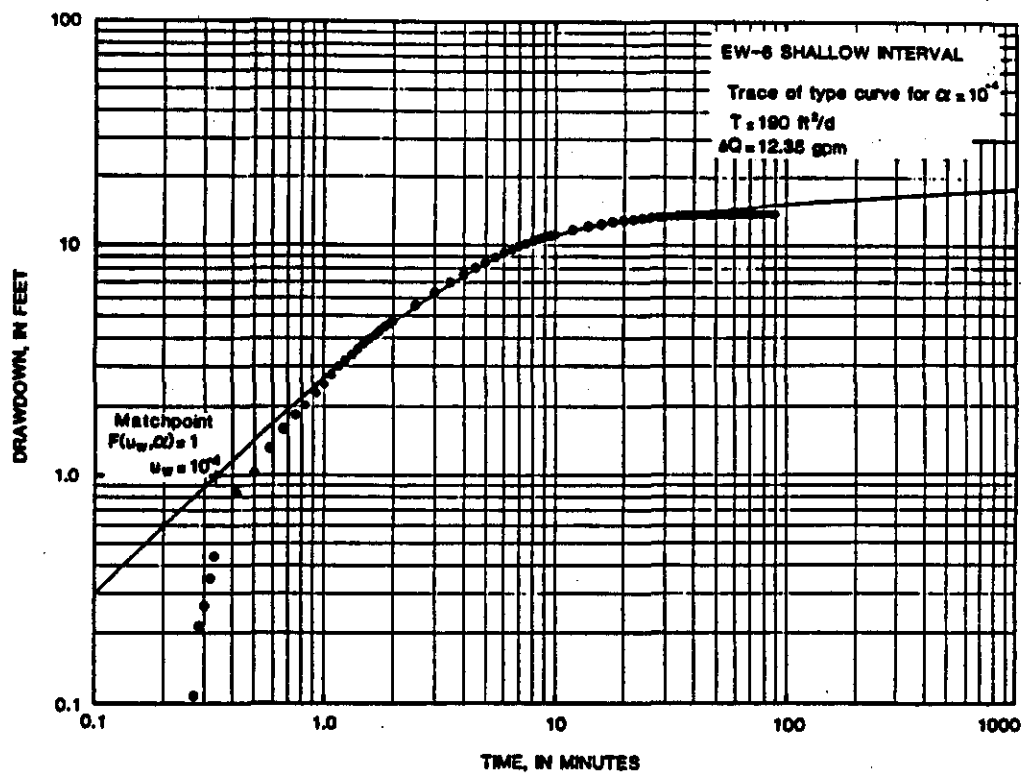


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ANALYSIS OF CONSTANT-RATE TEST DATA,  
WELL EW-5

FIGURE  
9

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ANALYSIS OF CONSTANT-RATE TEST DATA,  
WELL EW-6

FIGURE  
10

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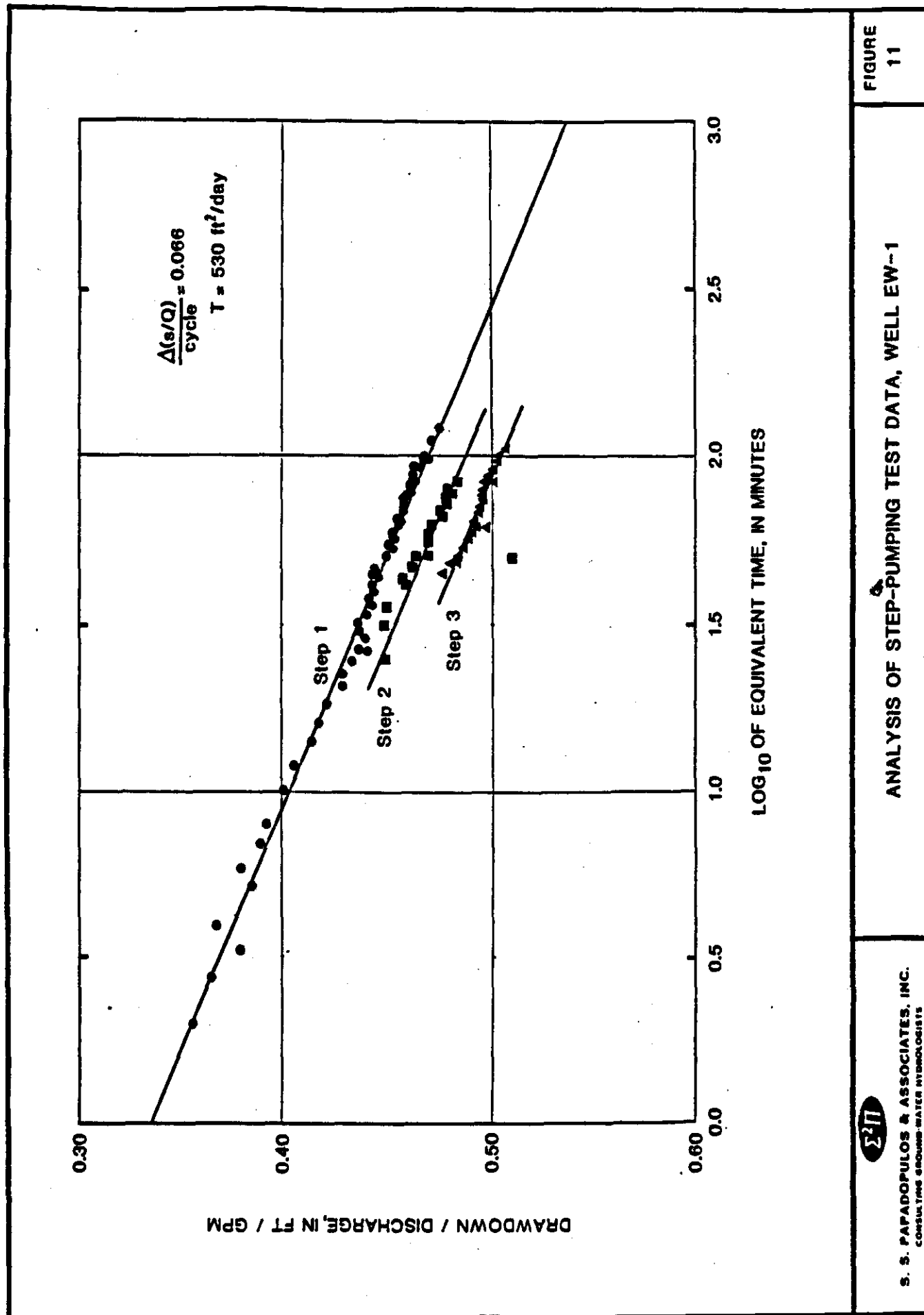
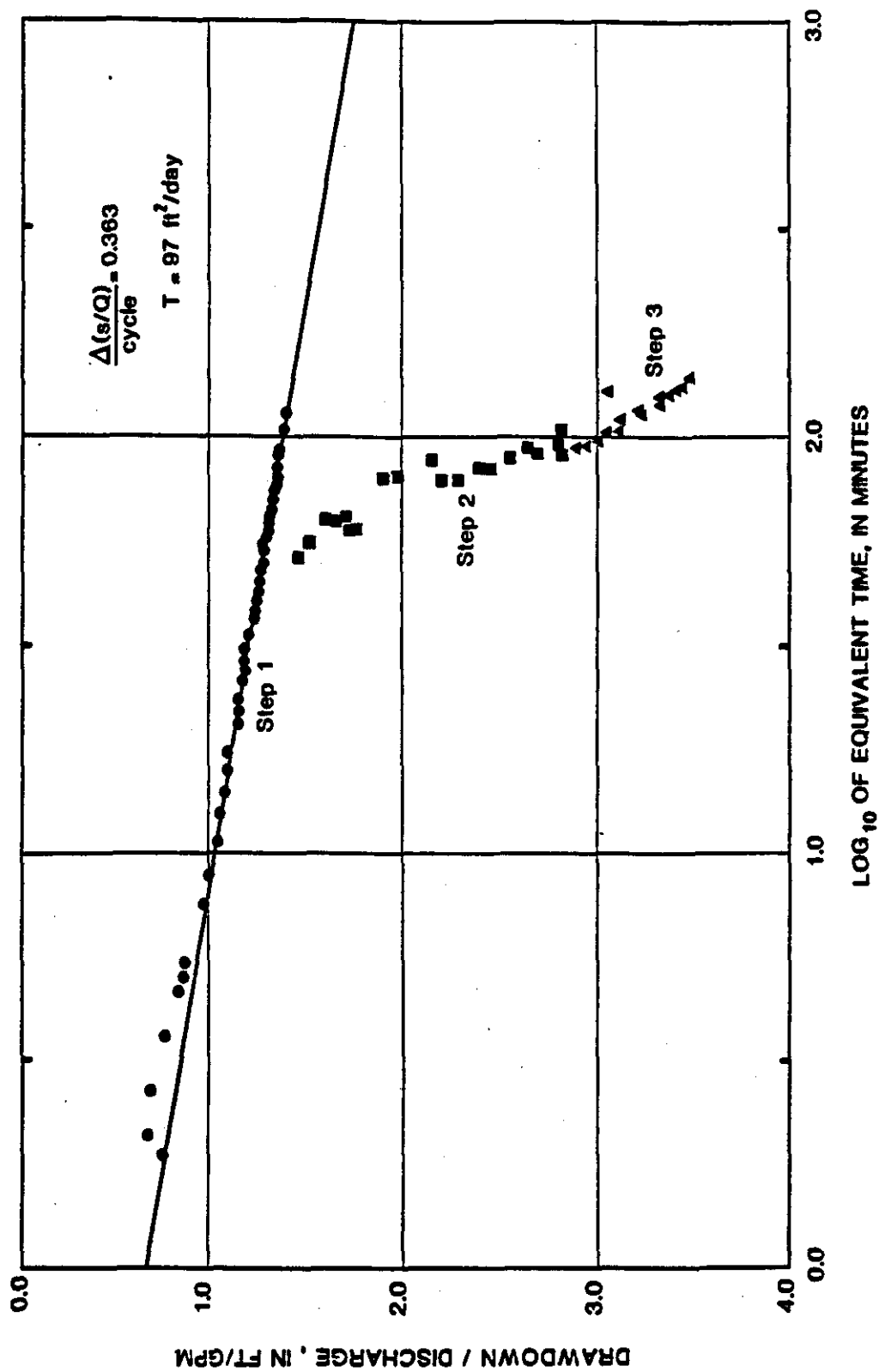


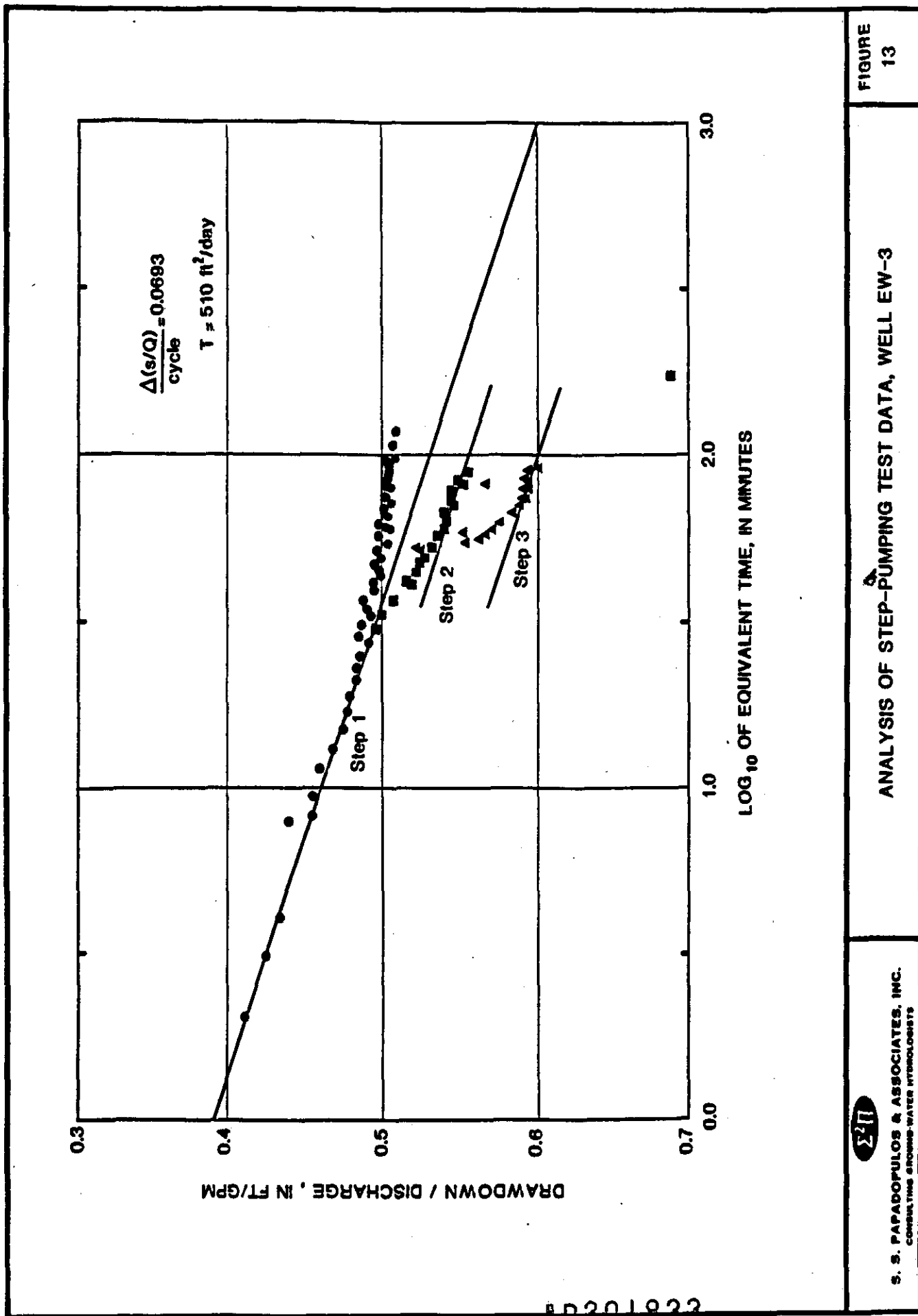
FIGURE  
11

ANALYSIS OF STEP-PUMPING TEST DATA, WELL EW-1



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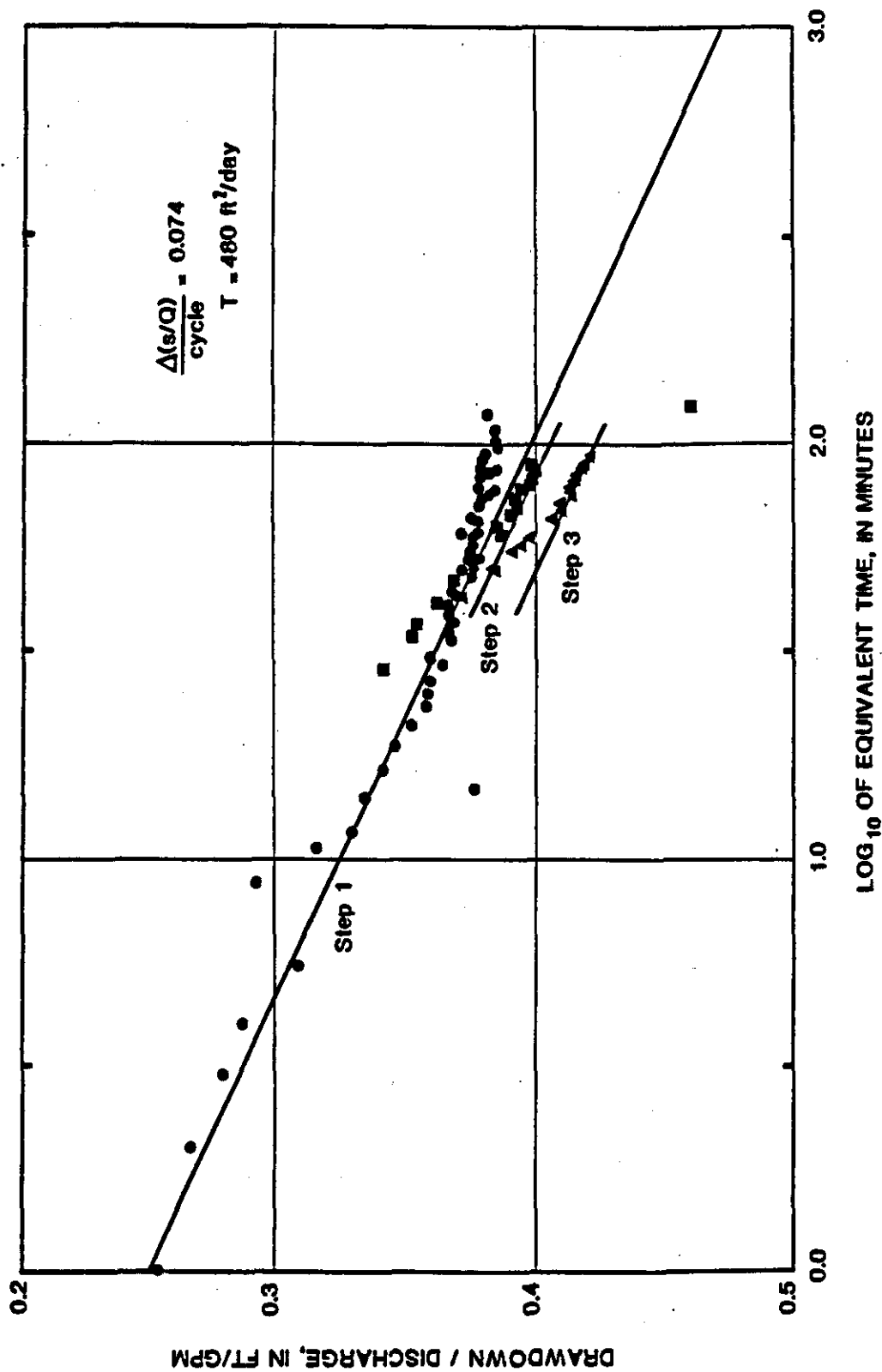


FIGURE  
14

ANALYSIS OF STEP-PUMPING TEST DATA, WELL EW-4

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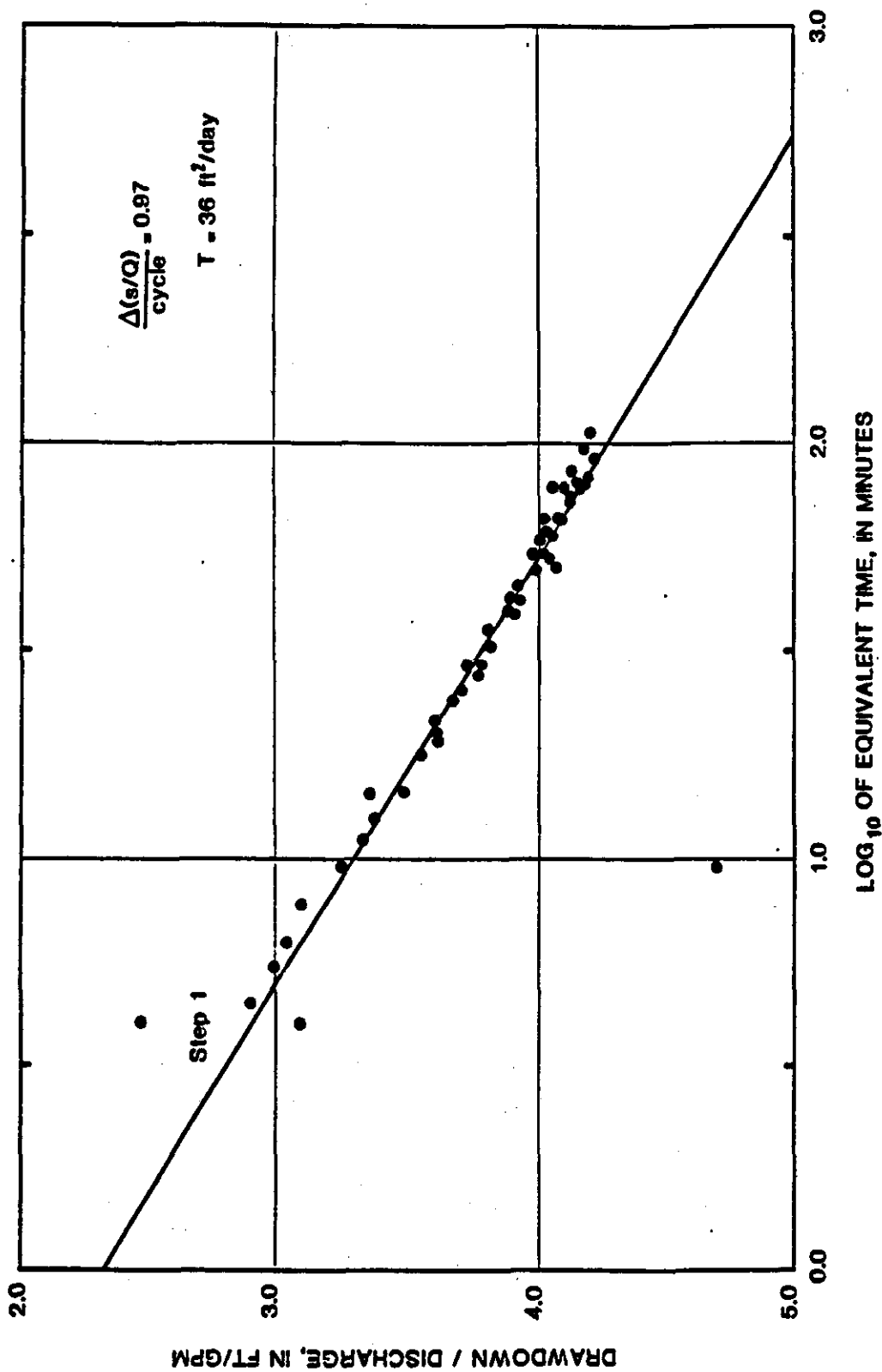


FIGURE  
15

ANALYSIS OF STEP-PUMPING TEST DATA, WELL EW-5

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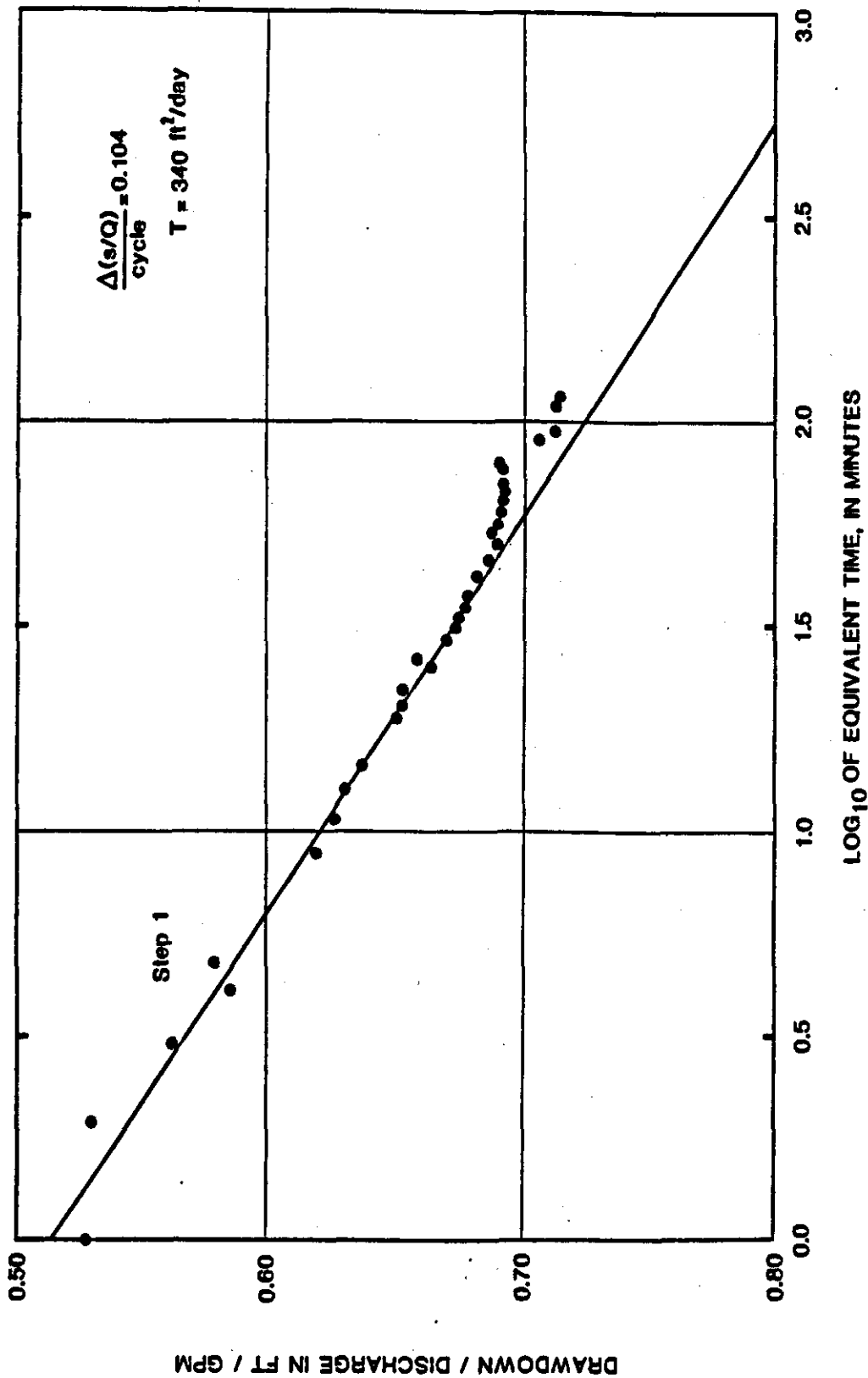


FIGURE  
16

ANALYSIS OF STEP-PUMPING TEST DATA, WELL EW-6

  
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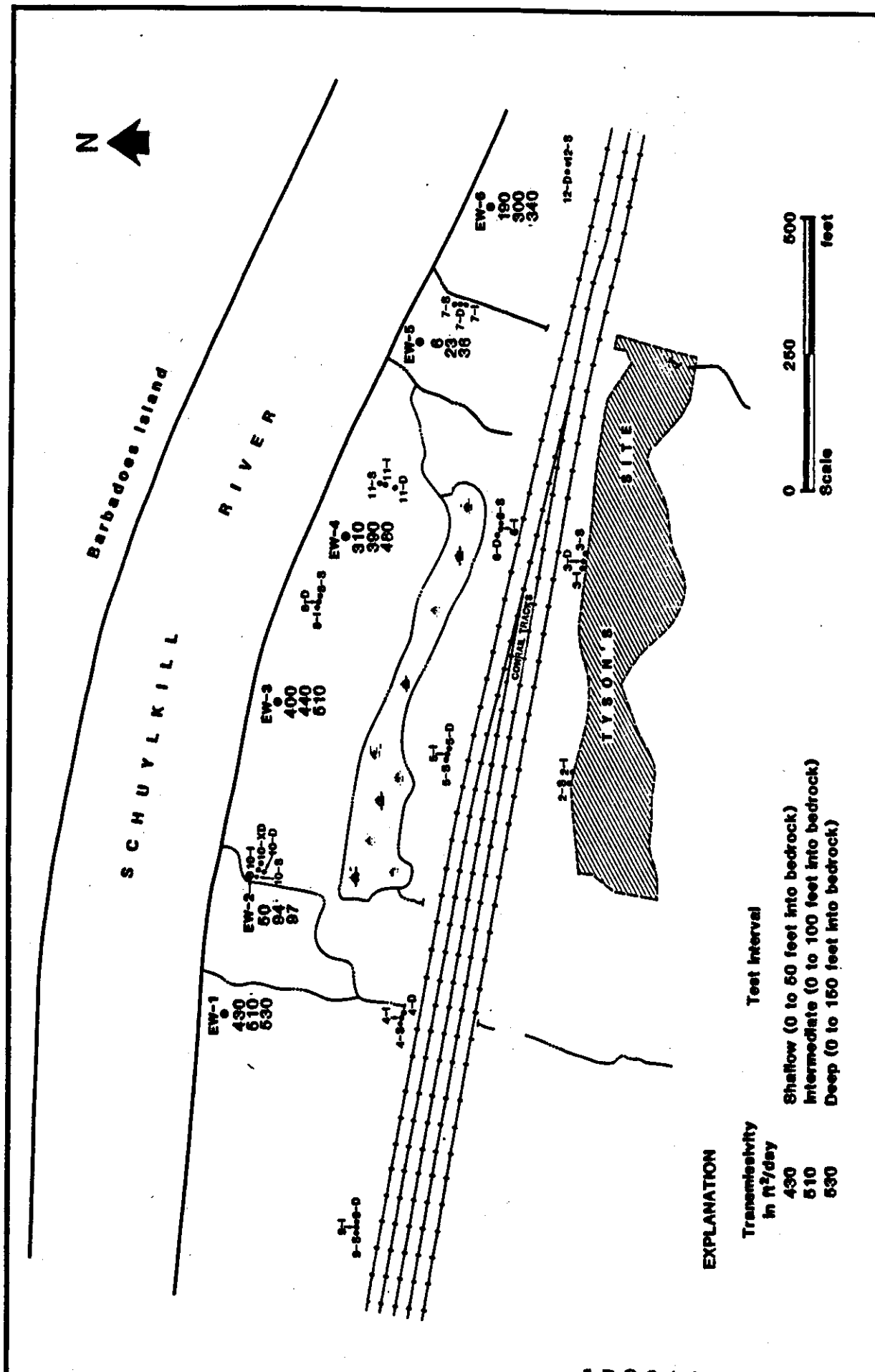
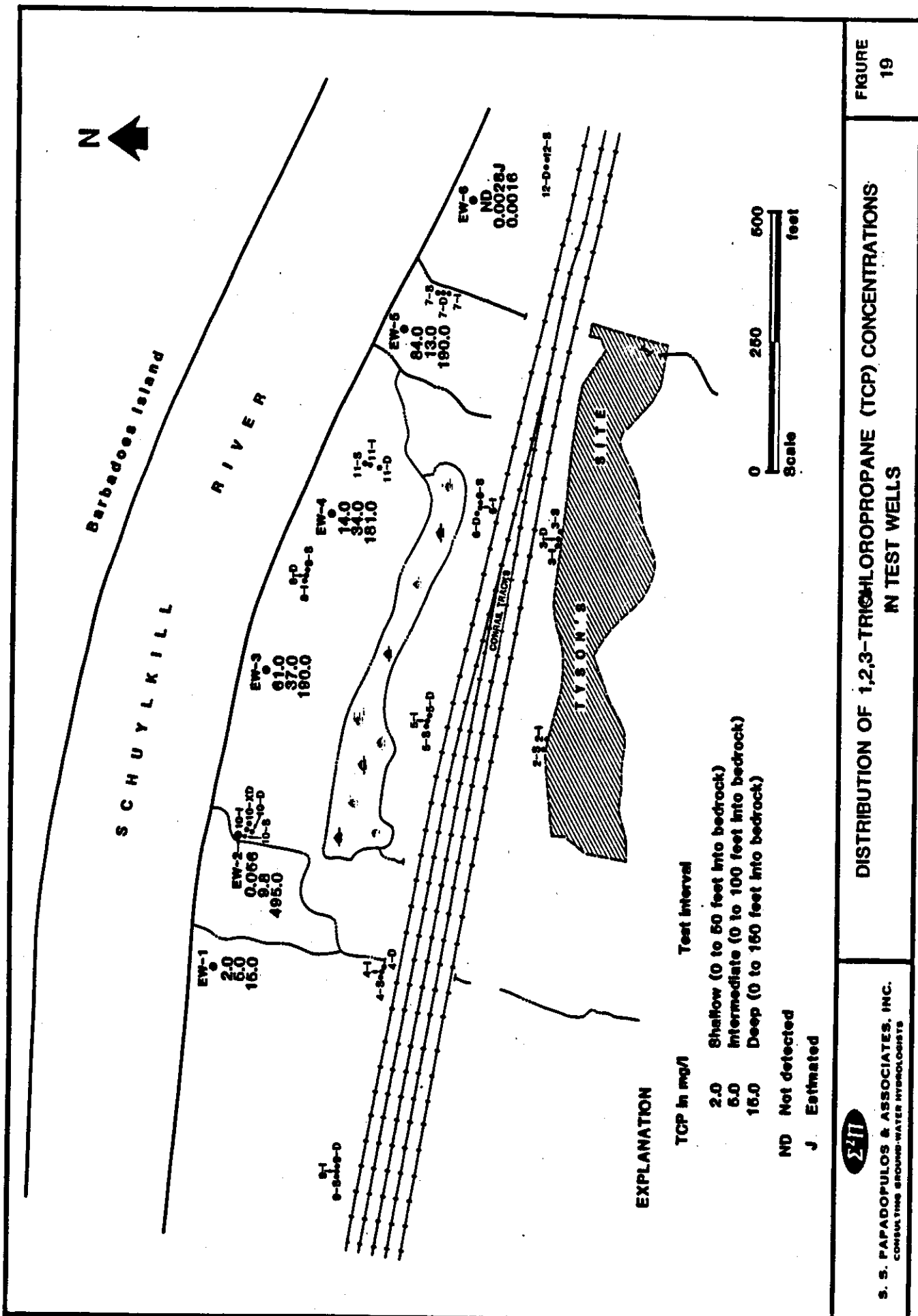
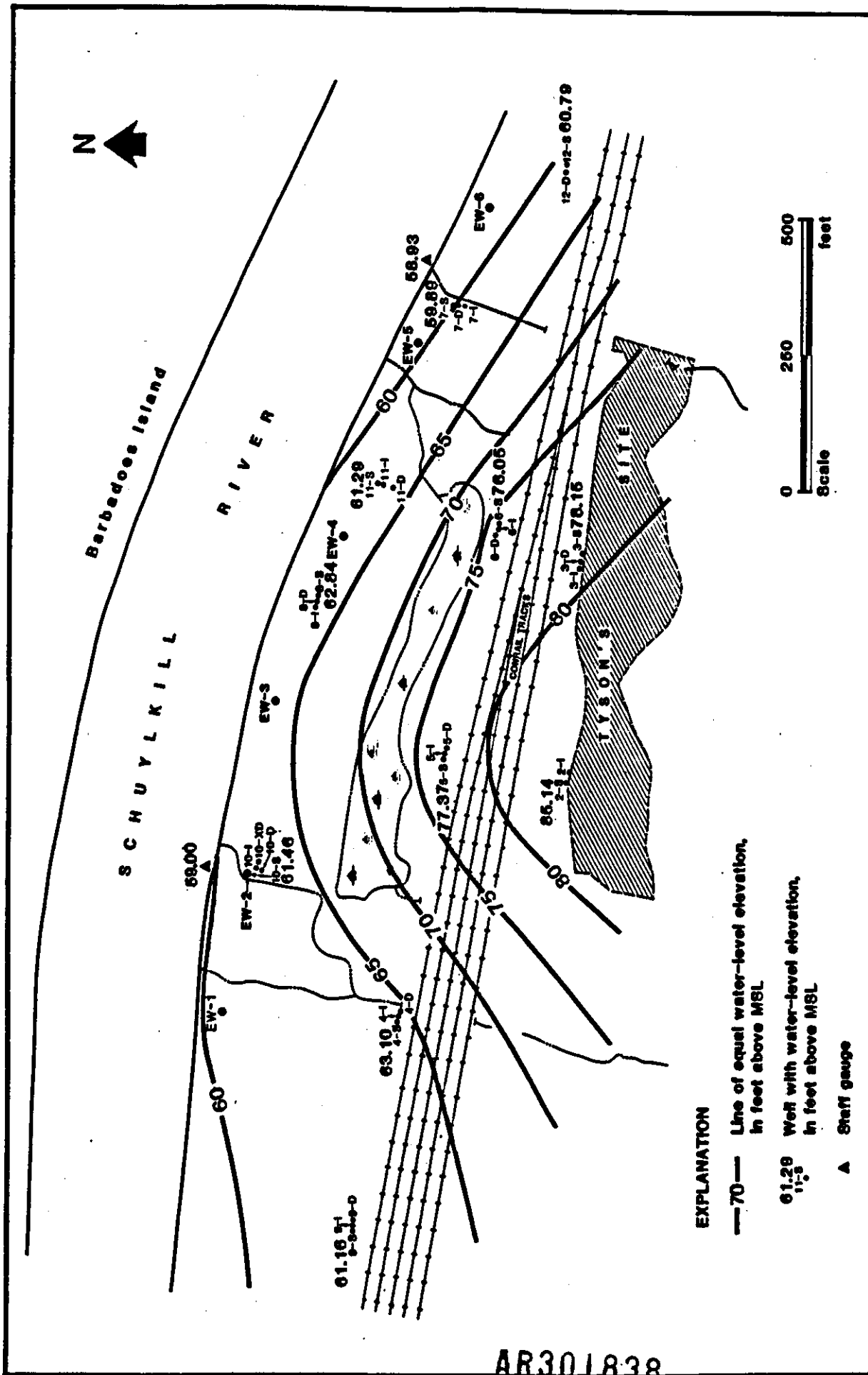


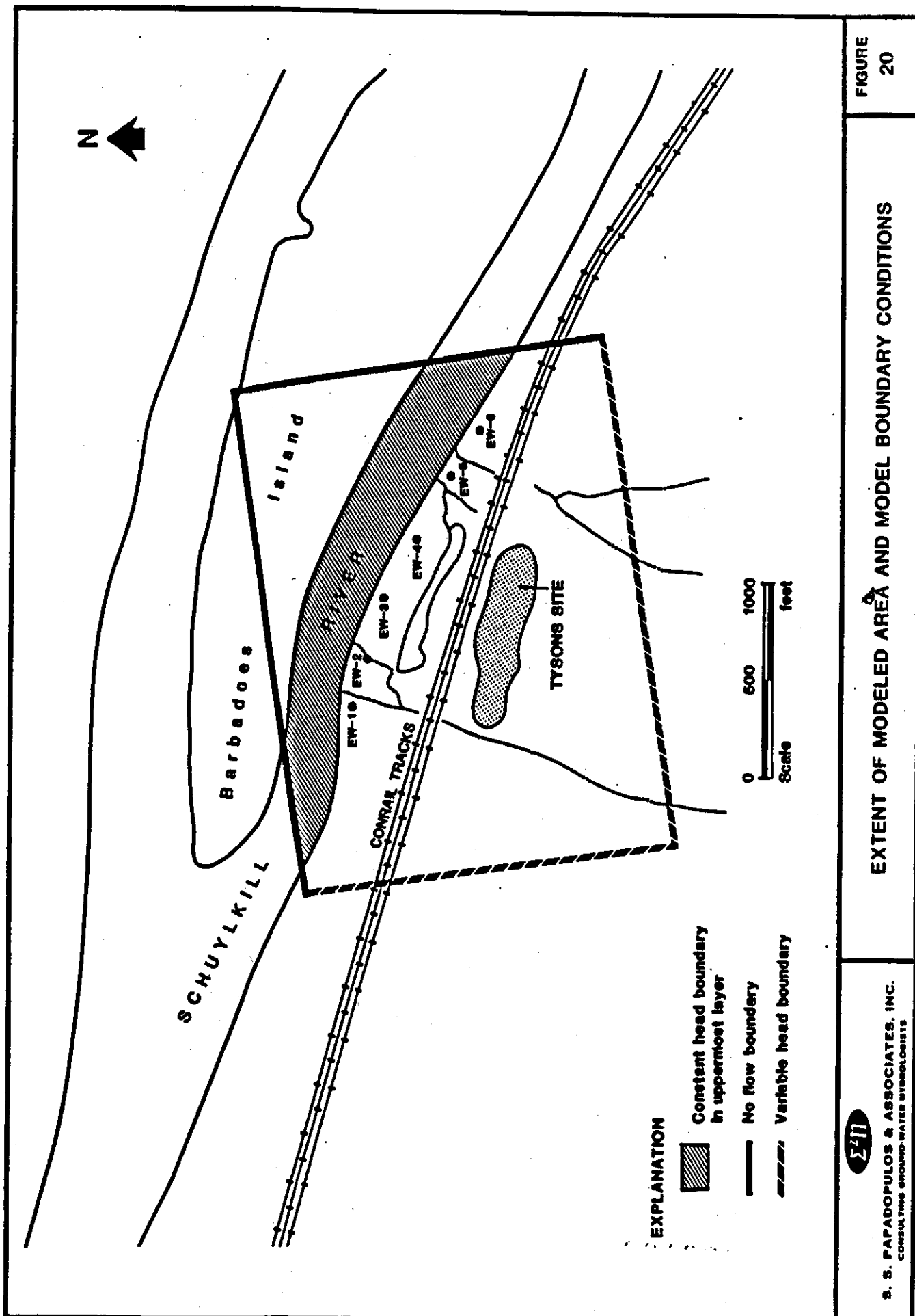
FIGURE 17

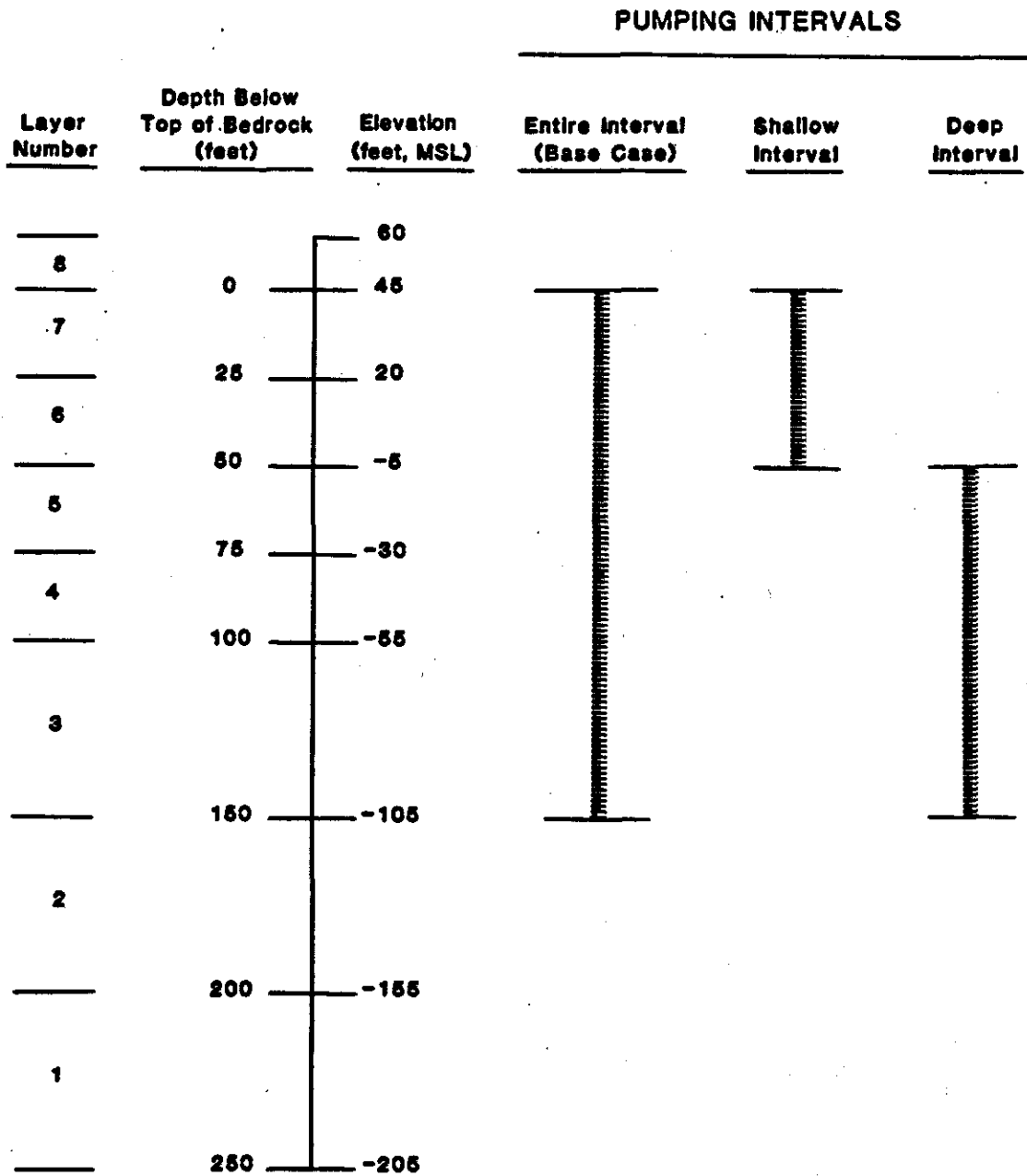
DISTRIBUTION OF TRANSMISSIVITIES IN TEST WELLS

AR301837







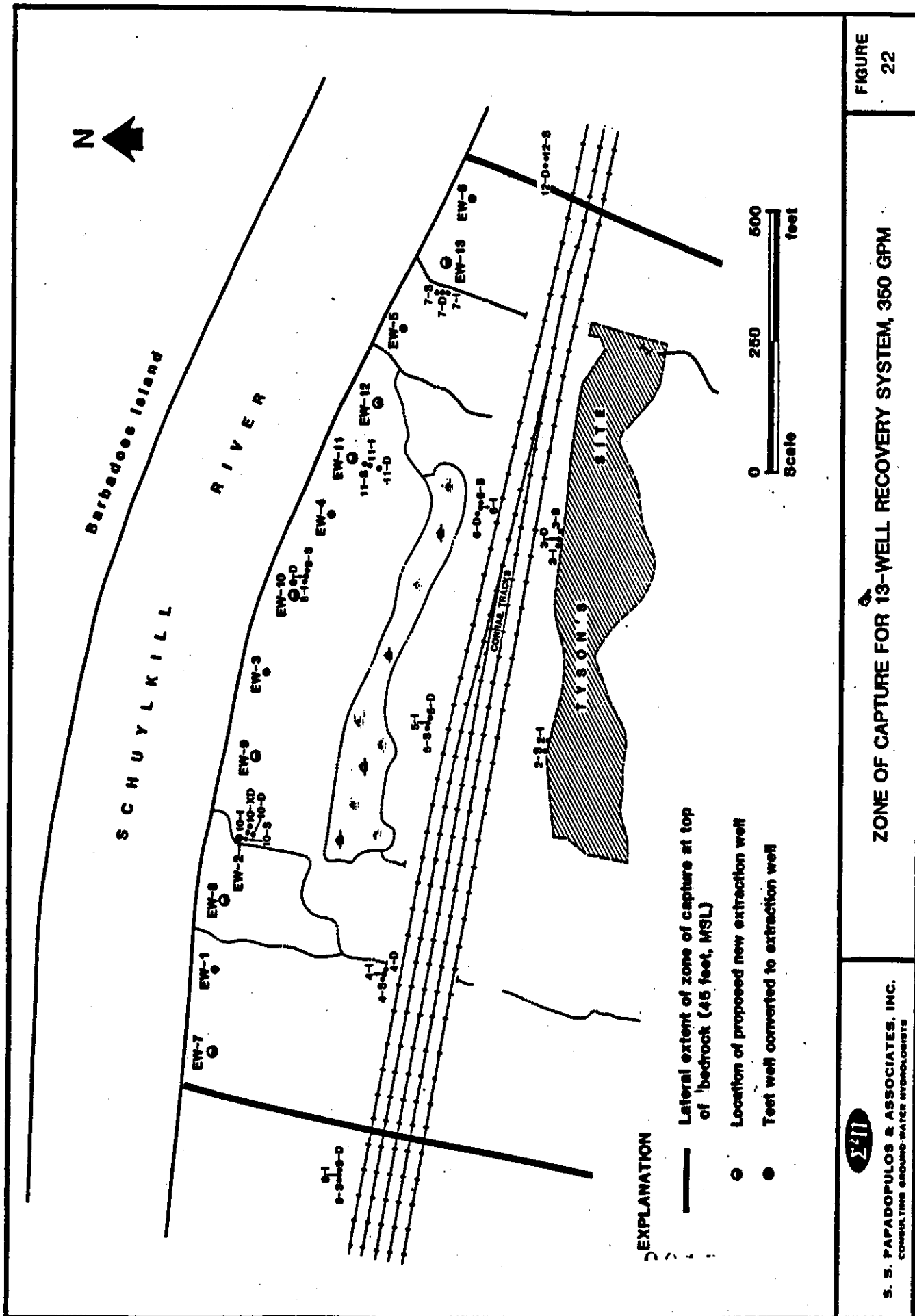


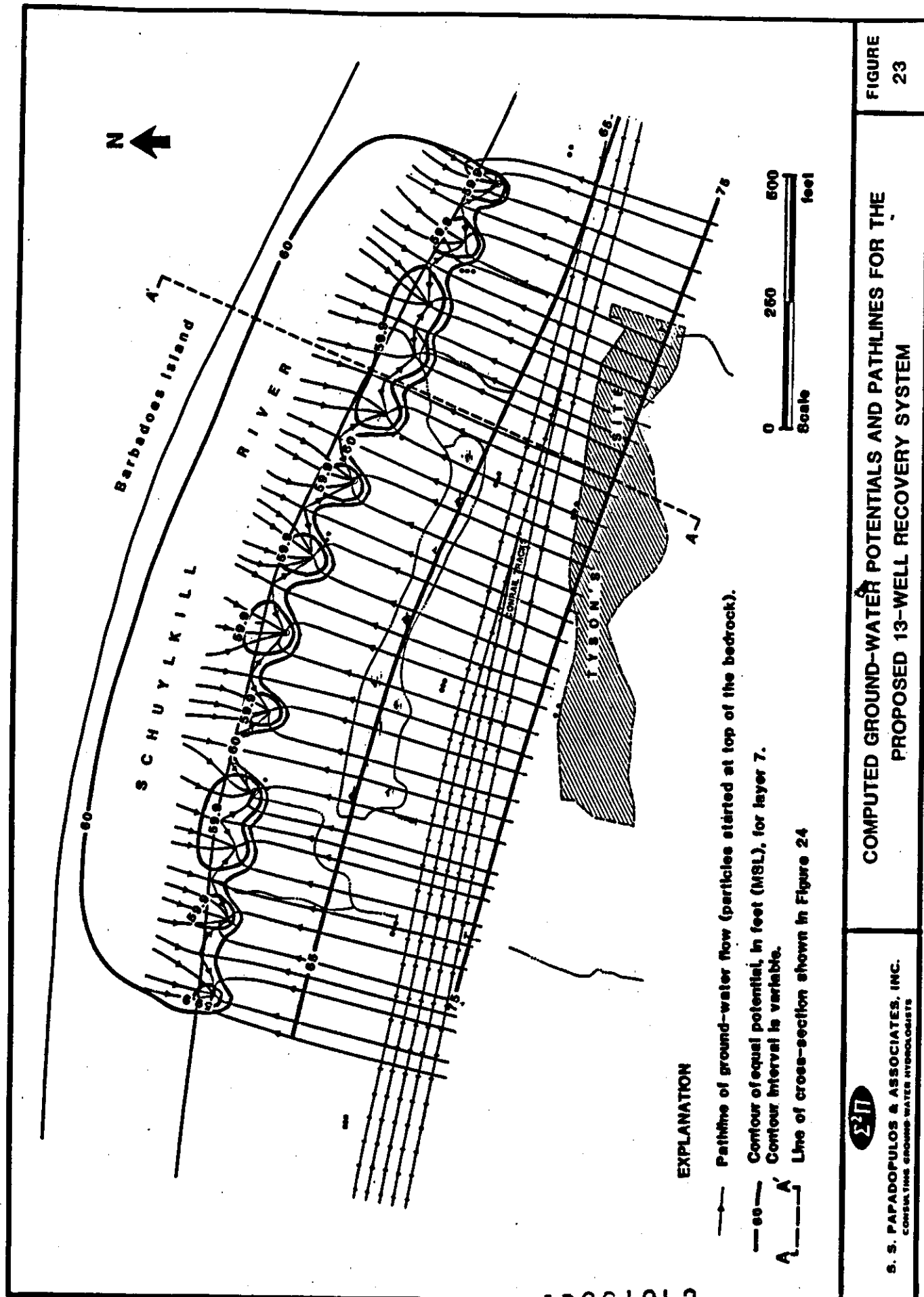
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**SCHEMATIC OF PUMPING SCENARIOS  
FOR EXTRACTION  
AT DIFFERENT INTERVALS**

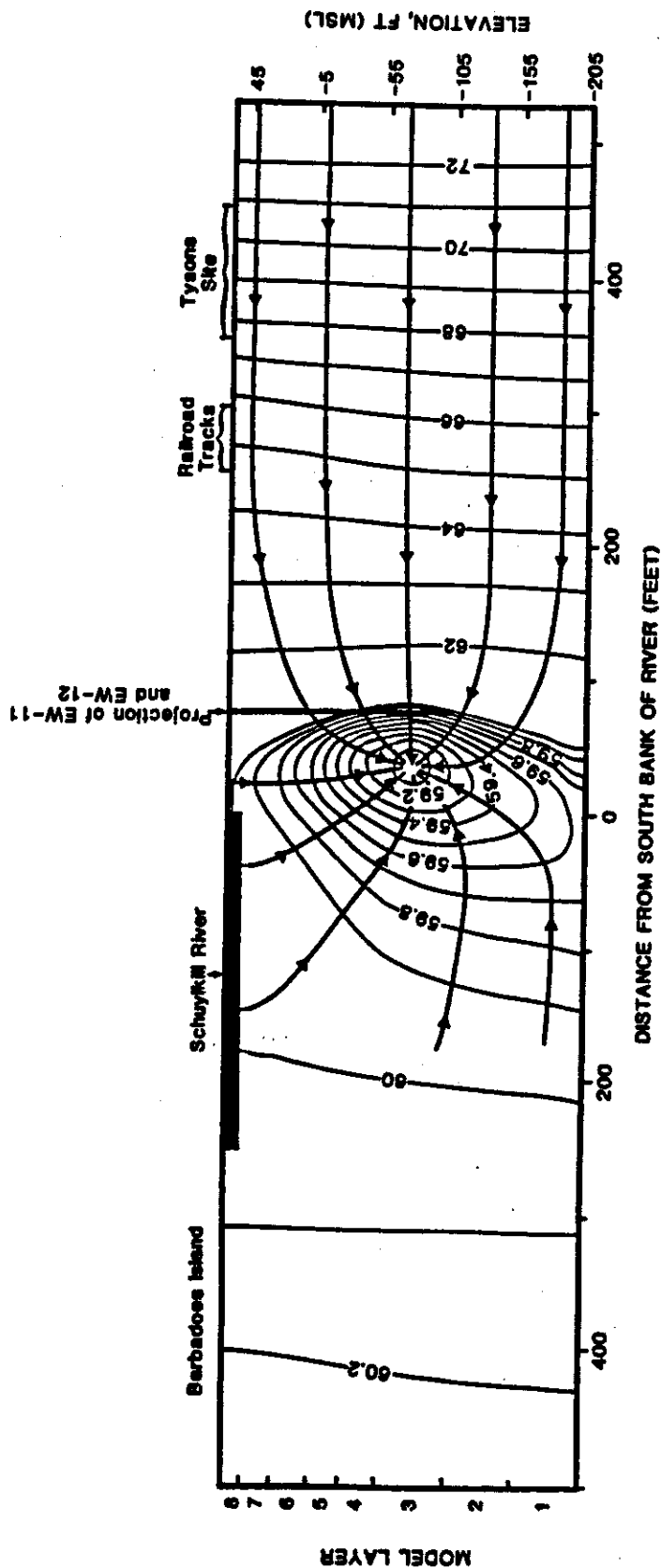
**FIGURE  
21**

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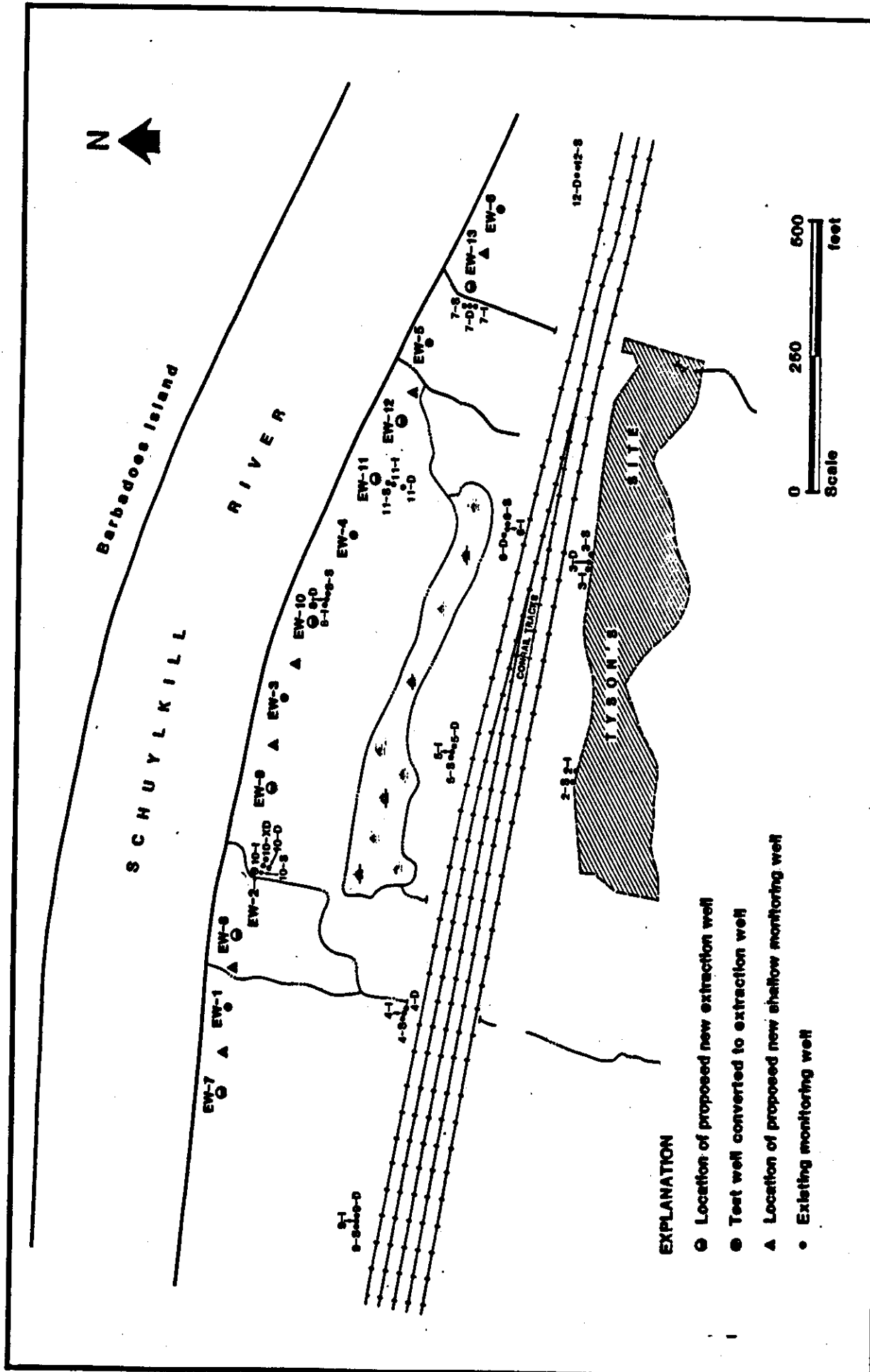


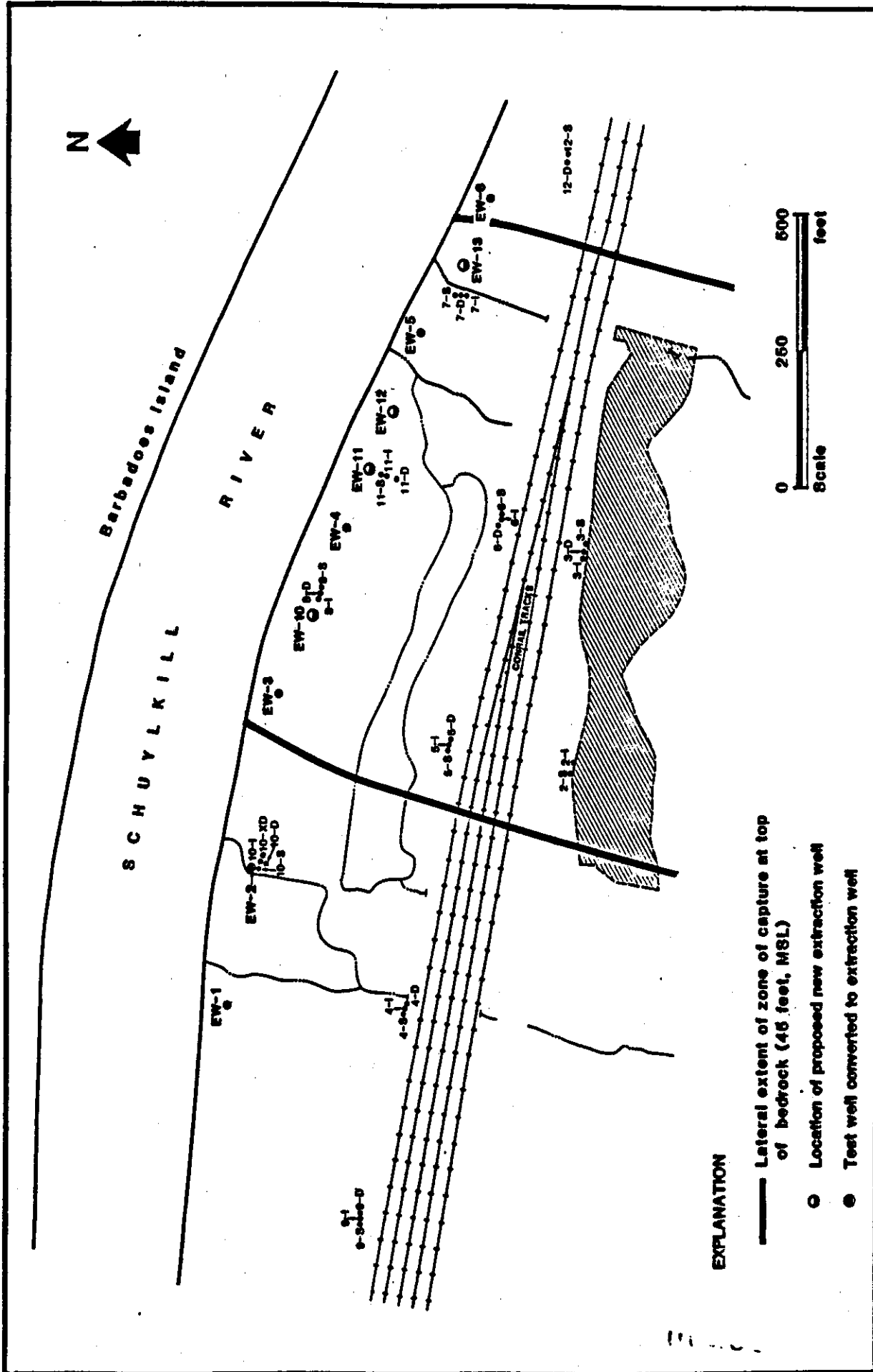
FIGURE  
25

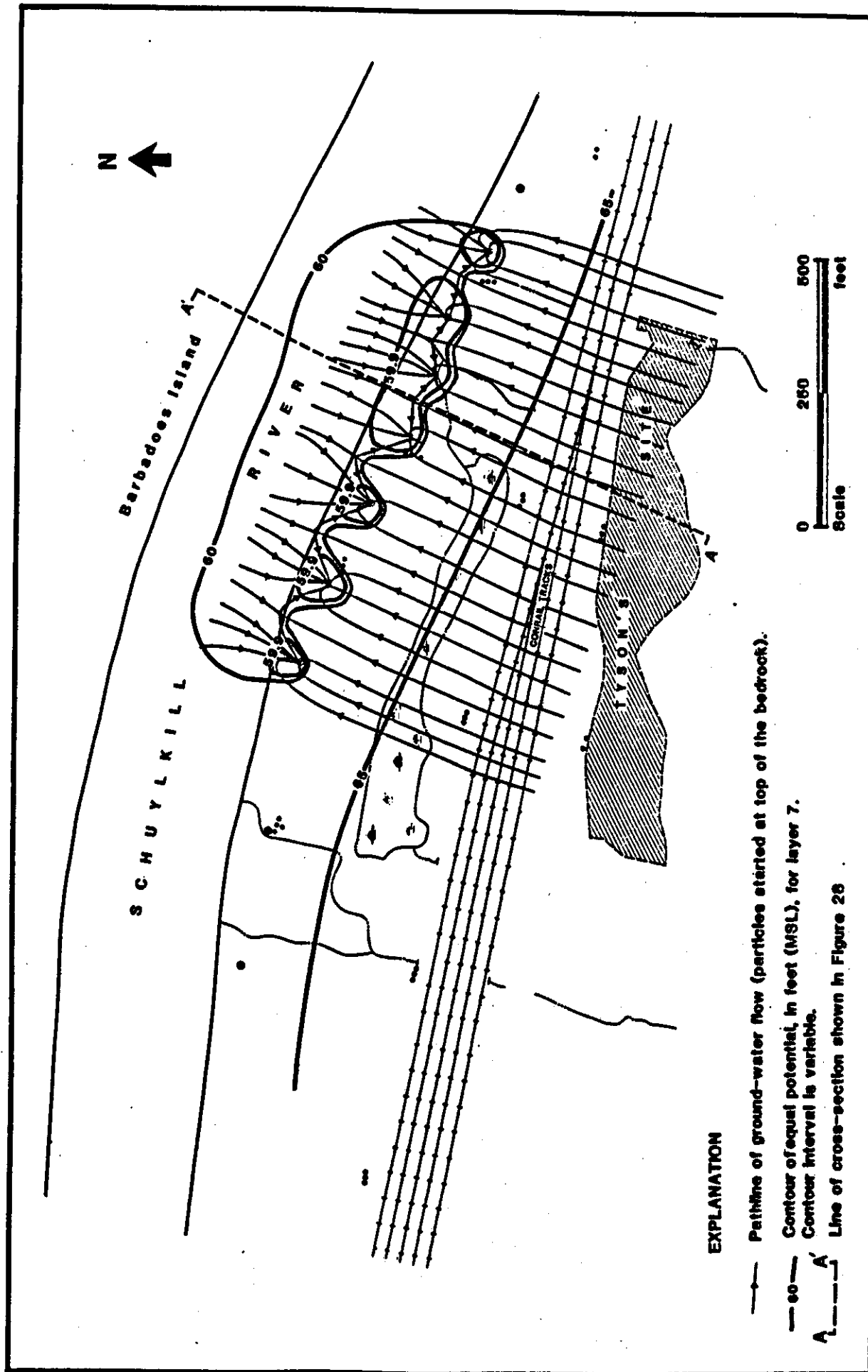
PROPOSED GROUND-WATER RECOVERY SYSTEM WITH MONITORING WELLS



S. S. PAPADOPOULOS & ASSOCIATES, INC.  
CONSULTING GROUND-WATER HYDROLOGISTS

AR301845





# EXPLANATION

— Pathline of ground-water flow (particles started at top of the bedrock).

— 60 — Contour of equal potential, in feet (MSL), for layer 7.

A — A' Contour interval is variable.

Line of cross-section shown in Figure 28

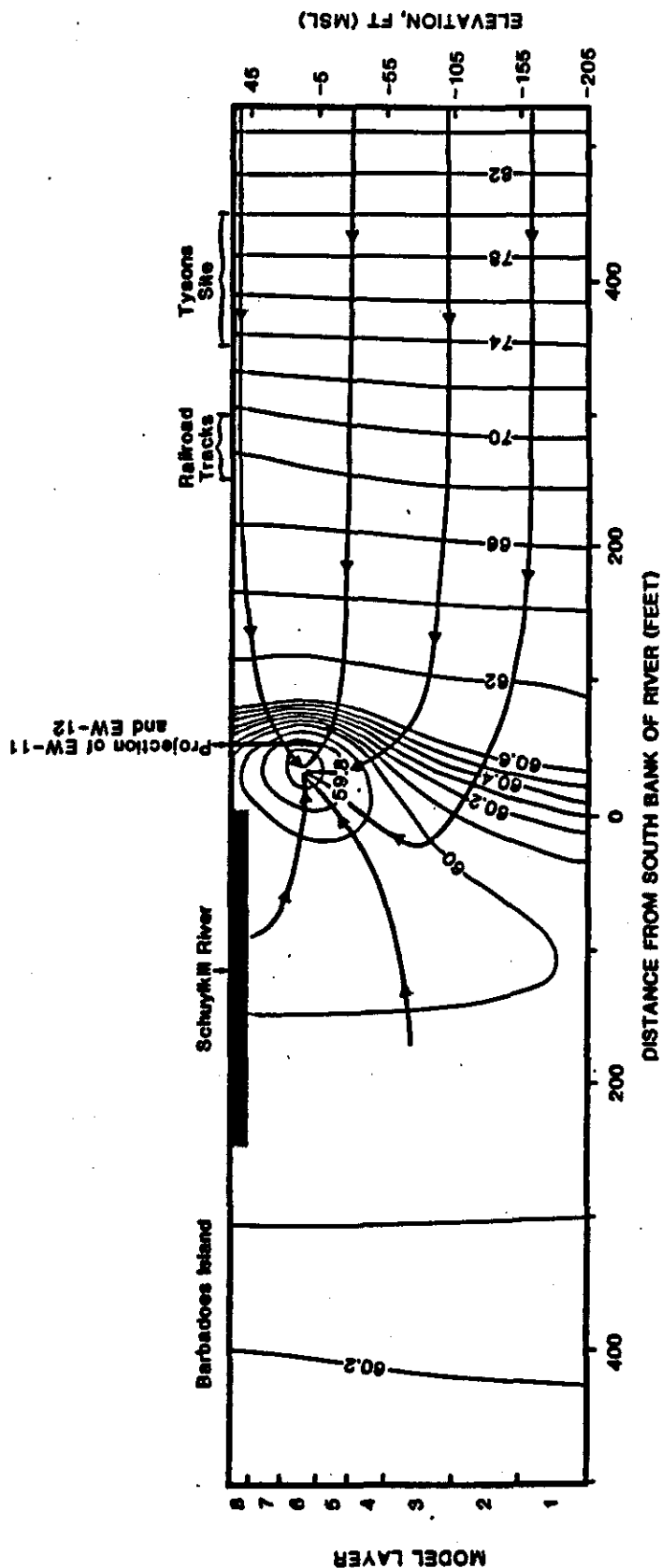


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COMPUTED GROUND-WATER POTENTIALS AND PATHLINES FOR THE  
PROPOSED 7-WELL INITIAL RECOVERY SYSTEM


FIGURE  
27

AR301847



# EXPLANATION

 Pathline of ground-water flow

 -60.2- Contour of equal potential, in feet (MSL).  
Contour Interval is variable



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CROSS-SECTIONAL VIEW OF COMPUTED GROUND-WATER POTENTIALS AND  
PATHLINES FOR THE PROPOSED 7-WELL INITIAL RECOVERY SYSTEM

FIGURE  
28

AR301848

**TABLES**

**TABLES**

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**AR301849**

TABLE 1

## TEST WELL CONSTRUCTION DETAILS

Well	Steel Casing Inside Diameter (inches)	Steel Casing Depth (ft below ls)	Open Interval <sup>1</sup> in Bedrock (ft below ls)	Depth to Bedrock Surface (ft below ls)	Survey Coordinates		Measuring Point Elevation <sup>2</sup> (ft above msl)
					----- Northing	----- Easting	
EW-1	8 3/4	30	30-180	23	10,676.54	9,723.39	71.16
EW-2	8 3/4	30	30-180	22	10,626.84	9,976.33	71.58
EW-3	8 3/4	25	25-185	20.5	10,578.49	10,293.61	69.91
EW-4	8 7/8	30	30-180	21	10,456.24	10,605.02	69.68
EW-5	8 7/8	30	30-180	20	10,322.80	10,961.50	67.48
EW-6	8 3/4	26	26-171	21	10,191.83	11,215.05	65.15

---

1 Open hole in bedrock is 8 1/2-inch diameter

2 Calculated by subtracting 0.02 ft from the surveyed elevation of the top of the casing cover

ls Land surface datum

msl Mean sea level

AR301850

**TABLE 2**  
**DATA FROM CONSTANT-RATE PUMPING TESTS**

Well	Interval Tested (ft below ls)	Length of Test (min)	Average Discharge Rate During Test (gpm)	Drawdown at End of Test (ft)	Specific Capacity at End of Test (gpm/ft)
EW-1	30-80	172	21.39	12.27	1.74
	30-130	190	18.71	7.67	2.44
EW-2	30-80	150	19.95	42.09	0.47
	30-130	140	19.95	23.46	0.85
EW-3	25-65	60	8.06	5.09	1.58
	25-125	180	22.25	13.60	1.64
EW-4	30-80	190	23.28	11.51	2.02
	30-130	190	21.80	8.86	2.46
EW-5	30-80	37	9.13	58.17	0.16
	30-130	211	5.14	27.68	0.19
EW-6	26-75	0-180	6.12	3.95	1.55
		180-275	18.50	18.34	1.01
	26-125	190	21.35	16.55	1.29

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TABLE 3  
DATA FROM STEP-PUMPING TESTS

Well	Step	Length of Step (min)	Average Discharge Rate During Step (gpm)	Drawdown at End of Step (ft)	Specific Capacity at End of Step (gpm/ft)
EW-1	1	120	20.00	9.43	2.12
	2	30	31.46	15.09	2.09
	3	42	38.82	19.61	1.98
EW-2	1	120	20.11	28.53	0.71
	2	32	28.78	72.89	0.40
	3	30	27.33	88.79	0.31
EW-3	1	120	20.65	10.46	1.97
	2	30	30.88	16.89	1.83
	3	30	37.70	22.52	1.67
EW-4	1	120	20.45	7.80	2.62
	2	30	30.20	11.96	2.53
	3	30	37.88	15.89	2.38
EW-5	1	120	5.03	20.82	0.24
	2	32	11.35	61.00	0.19
	3	32	13.93	132.12	0.11
EW-6	1	120	21.02	14.59	1.44
	2	30	27.32	21.37	1.28
	3	34	36.12	14.68	2.46

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TABLE 4  
WATER-LEVEL ELEVATIONS<sup>1</sup>

Well	Date	
	3/17/88	3/24/88
EW-1	60.76	60.85
EW-2	61.22	60.96
EW-3	60.82	60.59
EW-4	60.92	60.75
EW-5	59.58	59.48
EW-6	59.82	59.72
2-I	81.79	81.03
2-S	86.69	85.49
3-D	84.20	83.88
3-I	76.98	76.48
3-S	78.68	78.24
4-D	72.75	72.46
4-I	63.74	63.55
4-S	62.60	62.44
5-D	80.68	80.15
5-I	81.27	80.56
5-S	77.17	76.81
6-D	83.49	82.44
6-I	73.67	73.22
6-S	75.85	75.62
7-D	60.11	59.95
7-I	59.83	59.76
7-S	60.07	59.98
8-D	79.03	78.40
8-I	77.41	76.87
8-S	62.14	62.00
9-D	78.87	78.77
9-I	61.53	61.62
9-S	61.20	61.03
10-XD	76.13	76.13
10-D	60.66	60.56
10-I	61.32	61.08
10-S	61.29	61.06
11-D	76.94	75.88
11-I	77.34	76.74
11-S	60.90	60.73
12-D	60.10	59.96
12-S	61.11	60.95
MW-1	194.45	-----

<sup>1</sup> In feet above mean sea level

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TABLE 5  
VALUES OF TRANSMISSIVITY AT TEST WELL LOCATIONS

Well	Open Interval Tested (ft below ls)	Open Interval Transmissivity (ft <sup>2</sup> /d)	Bedrock Interval (ft below ls)	Bedrock Interval Transmissivity (ft <sup>2</sup> /d)	Total Transmissivity (ft <sup>2</sup> /d)
EW-1	30-80	430	30-80	430	530
	30-130	510	80-130	80	
	30-180	530	130-180	20	
EW-2	30-80	50	30-80	50	97
	30-130	94	80-130	44	
	30-180	97	130-180	3	
EW-3	25-65	400	25-65	400	510
	25-125	440	65-125	40	
	25-185	510	125-185	70	
EW-4	30-80	310	30-80	310	480
	30-130	390	80-130	80	
	30-180	480	130-180	90	
EW-5	30-80	6	30-80	6	36
	30-130	23	80-130	17	
	30-180	36	130-180	13	
EW-6	26-75	190	26-75	190	340
	26-125	300	75-125	110	
	26-171	340	125-171	40	

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TABLE 6  
CONCENTRATIONS OF SPECIFIC COMPOUNDS IN THE TEST WELLS  
(mg/L)

Compound	Depth Interval Sampled*	Well					
		EW-1	EW-2	EW-3	EW-4	EW-5	EW-6
1,2,3-Trichloropropane	30-80	2.000	0.056	61.000	14.000	84.000	ND
	30-130	5.000	9.800	37.000	34.000	13.000	0.0028J
	30-180	15.000	495.000	190.000	181.000	190.000	0.0016
Total Xylenes	30-80	0.120	0.035	3.400	0.560	0.210	ND
	30-130	0.099	0.360	1.700	1.200	0.270	ND
	30-180	0.093	2.800	5.800	5.100	0.280	ND
Ethylbenzene	30-80	0.042J	0.0059J	0.640J	0.082	0.028	ND
	30-130	0.037	ND	0.370	0.220J	0.035	ND
	30-180	0.028	0.580	0.780	0.830J	0.038	ND
Toluene	30-80	0.039J	0.0074J	0.660J	0.260	0.140	ND
	30-130	0.031	0.071J	0.370	0.840	0.160	ND
	30-180	0.027	0.750	0.690	2.200	0.170	0.002J

\* Approximate depth in feet below land surface

ND Not detected

J Estimated value

AR301855

**TABLE 7**  
**THICKNESS AND TRANSMISSIVITIES IN THREE-DIMENSIONAL FLOW MODEL**

<b>Layer Number</b>	<b>Thickness (ft)</b>	<b>Transmissivity (ft<sup>2</sup>/day)</b>	<b>Permeability (ft/day)</b>
8	15	670 <sup>1</sup> ; 120 <sup>2</sup>	45; 8
7	25	180	7.2
6	25	180	7.2
5	25	40	1.6
4	25	40	1.6
3	50	70	1.4
2	50	30	0.6
1	50	10	0.2

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1 Transmissivity of floodplain deposits near Schuylkill River

2 Transmissivity of colluvium and fill deposits

**AR301856**

TABLE 8  
INITIAL DISCHARGE RATES AND ESTIMATED DRAWDOWNS AND PUMPING LIFTS  
FOR THE PROPOSED RECOVERY SYSTEM

Well	Transmissivity (ft <sup>2</sup> /d)	Initial Discharge Rate (gpm)	Estimated Drawdown** (ft)	Estimated Pumping Lift*** (ft)
EW-1	530	45	40	50
EW-2	97	10	40	50
EW-3	510	40	40	50
EW-4	480	40	35	45
EW-5	36	5	45	55
EW-6	340	25	40	50
EW-7	500*	40	40	50
EW-8	310*	25	30	40
EW-9	300*	25	35	45
EW-10	500*	40	40	50
EW-11	330*	25	30	40
EW-12	180*	15	30	40
EW-13	190*	15	30	40

\* Estimated from test-determined transmissivity in adjacent wells.

\*\* Includes well losses.

\*\*\* Based on a 10-foot depth to the static water level; does not include losses in pump discharge column.

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**TABLE 9**  
**PROPOSED DISCHARGE RATES AND ESTIMATED DRAWDOWNS AND PUMPING LIFTS**  
**FOR THE INITIAL RECOVERY SYSTEM**

<b>Well</b>	<b>Transmissivity (ft<sup>2</sup>/d)</b>	<b>Discharge Rate (gpm)</b>	<b>Estimated Drawdown** (ft)</b>	<b>Estimated Pumping Lift*** (ft)</b>
EW-3	510	55	60	70
EW-4	480	55	50	60
EW-5	36	5	45	55
EW-10	355*	40	50	60
EW-11	210*	25	45	55
EW-12	110*	10	30	40
EW-13	100*	10	35	45

\* Estimated from the test-determined transmissivity of the upper 50 feet of bedrock in adjacent wells.

\*\* Includes well losses.

\*\*\* Based on a 10-foot depth to the static water level; does not include losses in pump discharge column.

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